

MULTIPLE-HEAD PHOSPHOR SCREEN SCANNER

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. Patent Application No. 09/260,890 filed March 2, 1999 (Atty. File No. 18482-000110), which claims the benefit of U.S. Provisional Patent Application No. 60/101,840 filed
10 September 25, 1998 (Atty. File No. 18482-000100), and the present application also claims the benefit of U.S. Provisional Patent Application Nos. _____ and _____ (Attorney Docket Nos. 18482-001000US and 18482-000900), both
15 filed September 22, 1999, the complete disclosures of which are hereby incorporated herein by reference in their entirety for all purposes.

TECHNICAL FIELD

20 The present invention relates to methods and devices for reading images stored on photostimulable media, and in particular to reading images stored on phosphor radiation screens.

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BACKGROUND OF THE INVENTION

The use of photostimulable phosphor image storage screens as a replacement for an x-ray film and other sensors is well known. Phosphor image screens work by trapping individual x-ray photons in a storage layer. The latent
30 image trapped in the screen can then be read by scanning the storage layer using a suitable wavelength excitation beam, preferably from a focussed laser. The laser excitation beam causes the screen to release the latent image in the form of

emitted stimuable phosphor light that is proportional to the x-ray energy applied to the screen during exposure. The emitted light is collected by an optical system and is converted into an electronic signal proportional to the emitted light. The electrical signal is then converted into a digital value and passed to a computer which generates and stores an image file. The image file can then be displayed as a representation of the original radiograph, with image enhancement software applied to augment the radiographic information.

Various known systems for moving a scanning head or directing a scanning beam across image or data storage screens are known. In one family of systems, an X-Y raster scan is taken as follows. The scanning head or beam first scans in a straight line across the screen in an X direction. The screen is then moved a short incremental distance in the Y direction. (Alternatively, the scanning head or the optics directing the beam can be moved incrementally in the Y direction). Thereafter, an X directional scan is repeated. Accordingly, by scanning back and forth in one direction, while intermittently advancing the screen (or re-directing the scanning beam), in a perpendicular direction, an X-Y raster scan is generated. In a second family of systems, the image or data storage screen is mounted to a rotating drum which is rotated about a center point in the plane of the screen while a scanning head is moved radially across the screen in a direction outwardly from the center point.

A problem common to both families of scanning systems is the problem of precisely controlling the movement of the scanning head, (or the movement of the optical system, such as a galvanometric mirror, directing the scanning beam). This is partially because the scanning head or scanning beam optics must be rapidly moved back and forth

in at least one direction with the speed of such movement being constantly and quickly changing. Accordingly, scanning heads or scanning beam optical systems which rapidly move back and forth are typically subject to
5 accelerations which cause problems including mechanical wear and failure and reduce read efficiency (i.e.: duty cycle) time to less than 100%. Accordingly, problems exist when attempting to accurately position such a moving scanning head or beam direction system to direct an incident beam at
10 a desired location on the phosphor screen.

A second problem of existing systems is that such systems are configured such that the response radiation emitted by the screen is not directed back through the same optical train to a light detector, and as such a first
15 optical train is required to direct and focus the incident light on the screen, and a second optical train is required to detect and measure the response radiation emitted by the screen.

It would instead be desirable to provide a system
20 for high speed scanning of a phosphor screen, (or any other photostimulable media), which moves a scanning beam head in a path across the surface of the phosphor screen to generate a raster scan, yet avoids the problems of controlling the back and forth movement of the scanning head across the
25 screen. It would also be desirable to avoid potential inaccuracies, control and wear and tear problems caused by acceleration forces moving such a scanning head back and forth in one or two directions, at the same time achieving 100% duty cycle read efficiency.

30 Moreover, it would be desirable to create a high speed scanning system which has minimal dead time during its operation such that a near continuous data stream can be generated as the phosphor screen is scanned.

Additionally, it would be desirable to create a high speed scanning system which does not require a transport mechanism which either moves the phosphor screen in two perpendicular directions (such as would be accomplished with an X-Y transport mechanism), or rotates the phosphor screen.

Additionally, it would be desirable to create a high speed scanning system which uses the same optical path for phosphor screen stimulation and data collection.

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SUMMARY OF THE INVENTION

The present invention provides systems and methods for scanning a photostimulable media, (which may preferably comprise a phosphor storage screen), with a rotating multi-head scanning device positioned thereover, or adjacent thereto. In one aspect of the present invention, a curved line raster scan is made of the phosphor screen, with the image data acquired in polar coordinate form. Using appropriate geometric algorithms, the polar coordinate form image is then transformed into an X-Y Cartesian form.

In preferred aspects of the invention, the rotating multi-head scanning device comprises a rotatable frame positioned over the phosphor screen. A plurality of radially extending optical trains are mounted to the rotatable frame such that laser light is directed downwardly toward the phosphor screen from scanning heads located at the outer perimeter of the rotatable frame, and such that response radiation emitted by the phosphor screen is received by the scanning heads and directed radially inwardly towards a centrally located light detector which may preferably comprise a photomultiplier tube, but may, for example, also comprise a photodiode.

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The frame is rotated about its center such that each of the scanning heads at the perimeter of the frame

pass over the phosphor screen in an arcuate path, one after another. As will be explained, each scanning head focuses its incident laser beam at positions which are equal distances from the center of the scanning device.

5 Concurrently with the rotation of the scanning device, the phosphor screen is preferably advanced in a Y direction underneath the rotating scanning device. In a first aspect of the invention, the center of the rotating scanning device is held at a fixed position above the phosphor screen while
10 a transport mechanism, which may comprise a series of rollers and guides or a transport mechanism, moves the phosphor screen under the rotating scanning device. In an alternate aspect of the invention, the transport mechanism is mounted to the rotating scanning device to move the
15 rotating scanning device across the surface of the stationary phosphor screen. In either case, a curved raster scan of the phosphor screen is generated by rotating a plurality of optical trains over the phosphor screen as the rotating scanning device is moved in one direction across
20 the surface of the phosphor screen.

In a preferred embodiment, the plurality of radially extending optical trains comprises three radially extending optical trains, each being spaced 120° apart from one another. In alternate embodiments, two radially
25 extending optical trains spaced 180° apart or four radially extending optical trains spaced 90° apart may also be used. Moreover, keeping within the scope of the present invention, more than four equally spaced apart optical trains may also be used.

30 In a preferred aspect of the invention, each optical train comprises its own laser source and a single photomultiplier tube is mounted at the center of the rotating scanning device for measuring the response radiation emitted by the phosphor screen.

Each of the plurality of optical trains is preferably operated in sequence such that only one scanning head is actively scanning across the surface of the phosphor screen at a time. By activating the individual laser sources dedicated to each optical train in sequence, (or by selectively receiving the data signal from each optical train in sequence when the individual laser sources dedicated to each optical train are all operating simultaneously), an advantage of the present invention is that only one centrally-located photomultiplier tube needs to be used to gather image data from each of the three separate optical trains. By using a single centrally mounted photomultiplier tube with the plurality of scanning head optical trains, an advantage is not having to calibrate the correlation among more than one photomultiplier tube. Moreover, by using only one single photomultiplier tube, (as opposed to a separate light detector for each optical train), a lower cost system is provided having a greater mean statistical system reliability.

In various preferred embodiments of the optical train, each optical train comprises a laser located proximal to the center of the rotatable frame and a reflecting mirror located at the outer perimeter of the rotatable frame. A dichroic mirror is used to separate incident laser light from response radiation emitted by the phosphor screen such that only the response radiation is directed to a photomultiplier tube. In various aspects of these embodiments, the dichroic mirror may either be mounted proximal to the center of the rotatable frame (near the laser) or alternatively may be mounted at the outer perimeter of the rotatable frame.

In other preferred embodiments of the optical train, each optical train comprises a laser located at the outer perimeter of the optical train. A dichroic mirror

mounted at the outer perimeter of the optical train is used to separate incident laser light from response radiation emitted by the phosphor screen such that only the response radiation is directed to the photomultiplier tube.

5 In a preferred aspect of the embodiment of the present invention using three optical trains spaced 120° apart, the rotating three-head scanning device is constructed such that the "optical radius", (defined herein as the radial distance from the center of the scanning
10 device to the focal point of the laser beam on the phosphor screen under each scanning head) is at least 1.1547 (ie: $1/\text{SIN}(60^\circ)$) times one-half the width of the phosphor storage screen. Assuming the scanning heads are positioned at the perimeter of the scanning device, 120 degrees apart, and
15 that the focal point of each laser beam lies exactly at the perimeter of the scanning device, then the scanning device will have an optical diameter of 1.1547 times the width of the phosphor screen. (The "optical diameter" being defined herein as double the distance of the "optical radius"). By
20 mounting the scanning heads such that the optical diameter of the system is exactly 1.1547 times the width of the phosphor storage screen, a number of important advantages result. For example, when rotating three equidistant, 120 degree spaced-apart scanning heads above the phosphor
25 storage screen, each of the separate scanning heads will pass completely over the phosphor screen (in an arcuate path) one after another in sequence. Accordingly, immediately after the first scanning head scans completely across the phosphor screen and reaches a position just off
30 the surface of the phosphor screen, a second scanning head will simultaneously move into position to generate its own arcuate scan across the surface of the phosphor screen, thereby achieving 100% duty cycle read efficiency. Similarly, after the second scanning head has completed its

scan across the phosphor screen, the third scanning head will move into position to generate its own arcuate scan across the surface of the phosphor screen.

5 An additional advantage of having the "optical radius", (ie the radial distance from the center of the scanning device to the focal point of the laser beam on the phosphor screen under each scanning head) be 1.1547 times one-half the width of the phosphor storage screen is that destructive reading is avoided at the edges of the phosphor
10 screen, as will be explained.

In additional aspects of the three head design of the present invention, the system's optical radius is somewhat larger than 1.1547 times one-half the width of the phosphor storage screen. When using three equidistantly
15 spaced-apart scanning heads, a "data time gap" will exist between each of the scanning heads. This "data time gap" is caused by the fact that the first scanning head will have passed some distance off the surface of the phosphor screen before the second scanning head passes onto the surface of
20 the phosphor screen. It may be desirable to have such a data time gap between the signals read by each of the various scanning heads. For example, such a data time gap can be used to initialize the data gathering system before each scanning head passes over the surface of the phosphor
25 screen. Such a data time gap can also be used to clearly separate the signals between each of the three scanning heads.

When using three 120 degree spaced apart optical trains having scanning heads with the system's optical
30 radius being less than 1.1547 times one-half the width of the phosphor storage screen, more than one scanning head will be passing across the surface of the phosphor screen at a time. In such an arrangement, it would not be possible to

use a single centrally located photomultiplier tube to distinguish between the signals of the three scanning heads.

When using three separate scanning heads, (spaced apart at 120 degrees to one another), with the system's optical radius being 1.1547 times one-half the width of the phosphor storage screen, each scanning head will scan in arcuate path across the screen, one at a time. Therefore, it is possible to have each individual scanning head scan sequentially such that very soon after one scanning head completes an arcuate raster scan across the surface of the phosphor screen, the next scanning head will complete a similar raster scan across the phosphor screen surface.

In one aspect, the dedicated laser for each optical train is turned on and off in sequence such that only one laser (i.e.: the laser in the optical train actively scanning over the surface of the phosphor screen) is activated at a time.

Alternatively, it is also possible to have the dedicated laser in each of the optical trains operating at the same time. In this case, mechanical shielding of the phosphor screen is used such that only one optical train's laser beam reaches the surface of the phosphor screen at a time, as that optical train scans across the surface of the screen, thereby eliminating the need to sequentially activate and deactivate the individual lasers in each optical train.

In a preferred aspect, such shielding may comprise a pair of radially disposed knife edges which are fixed to the frame of the scanner which do not rotate with the scanning disk. In preferred aspects, mechanical means may be provided to permit the exact angle between the two radial knife edges to be adjusted. It is to be understood that the preferred knife edged blades could be replaced with any other suitably shaped blocking structure. When using three

or more than three scanning heads, the angle between the knife edges will be slightly less than $360^\circ/n$ where n is the number of radially extending optical trains.

In various aspects, the present invention
5 comprises an optical system which includes a single non-rotating (i.e., stationary) laser. A polyhedral prism with reflective surfaces enables the single stationary laser to be used in a multi-head optical system, offering advantages of lower cost, complexity and rotating mass.

10 In alternative aspects, the optical train comprises an optical fiber wave guide which carries the light signals from the scanning heads to a centrally located photomultiplier tube. An advantage of such optical fiber wave guides are that they enable reduction in the diameter
15 of a central passageway through the disk bearing. In addition, such optical fiber wave guides avoid the need for the photomultiplier tube to be located in an open axially extending channel in the center of the scan disk bearing.

Using a one dimensional transport mechanism, the
20 phosphor screen can be moved relative to the rotating multi-head scanning device such that the arcuate path of the scanning head over the phosphor screen will advance such that a curved raster scan will be generated. Using appropriate software and algorithms, the curved raster scan
25 can then be converted into a system of linear X-Y coordinates such that the image stored on a phosphor radiation screen can accurately be reproduced.

As such, the present invention provides a high
30 speed system for moving a phosphor screen under multiple scanning heads, wherein each of the scanning heads are maintained at fixed positions on the frame of the scanning device. Accordingly, an important feature of the present invention is that it is not necessary to repeatedly move scanning heads radially back and forth on the scanning

device as the various scanning heads pass over the phosphor screen. This substantially reduces wear and tear on the system providing a long-life, high-speed device which has substantially fewer moving parts than existing scanner designs. Moreover, the present invention is balanced and has a slim aerodynamic profile for high speed rotation about its center.

In an alternate aspect of the invention, the phosphor screen is oriented perpendicular to the plane of the scanning device with the phosphor screen being wrapped partially around the edge of the scanning device. When using the present three head scanner design, the phosphor screen is preferably wrapped with its edges spaced 120 degrees apart relative to the scanning device. When using a two head scanner, the phosphor screen is preferably wrapped with its edges spaced 180° apart relative to the scanning device; and when using a four head scanner, the phosphor screen is preferably wrapped with its edges spaced 90° apart relative to the scanning device. (In such arrangements, only one scanning head will be passing over the surface of the phosphor screen at a time). In these alternate aspects of the invention, each scanning head focuses the laser beam radially outwardly in a direction parallel to the plane of the scanning device. In the various aspects of the present system, the only necessary moving parts are a system to rotate the scanning device about its central axis and a system to advance the motion of the phosphor screen in one dimension. By moving the phosphor screen relative to the rotating scanning device, high resolution scanning can be achieved as the phosphor screen can be advanced in very small increments relative to the path of the scanning head passing thereover. Accordingly, a pixel by pixel resolution of the image can be derived.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a top plan view of a first preferred embodiment of the present invention incorporating three radially extending optical trains mounted at 120° to one another, with the "optical radius" (ie: the radial distance from the center of the scanning device to the focal point of the laser beam under each scanning head) being 1.1547 times one-half the width of the phosphor screen.

Fig. 1B is a top plan view of a second preferred embodiment of the present invention incorporating three radially extending optical trains mounted at 120° to one another, with the optical radius being slightly greater than 1.1547 times one-half the width of the phosphor screen.

Fig. 2 is a side sectional view taken along the line 2-2 in Fig. 1A.

Fig. 3 is an enlarged view of a portion of Fig. 2.

Fig. 4A is a schematic representation of the preferred optical train shown in Fig. 3.

Fig. 4B is a schematic representation of an alternative preferred optical train.

Fig. 4C is a schematic representation of yet another preferred optical train.

Fig. 4D is a schematic representation of an alternative preferred optical train.

Fig. 4E is a schematic representation of yet another preferred optical train.

Fig. 4F is a schematic representation of yet another preferred optical train.

Fig. 5 is a geometric representation of incremental movement of an arcuate line across the surface of a phosphor screen.

Figs. 6A and 6B show a two head scanning device.

Fig. 7 shows a four head scanning device.

Fig. 8 shows a six head scanning device.

Fig. 9 is a top plan view of an alternate arrangement of the present invention with the phosphor screen disposed perpendicular to the scanning device and partially wrapped around the perimeter of the scanning device.

Fig. 10 is a cut away side view corresponding to Fig. 9.

Fig. 11 is an illustration of successive scans taken across the phosphor screen of Fig. 9.

Fig. 12 is a top plan view of another preferred embodiment of the present invention incorporating three radially extending optical trains mounted at 120° to one another.

Fig. 13 shows a view taken along line 13-13 in Fig. 1A, (but having scanning head 26 rotated to a position over the bi-cell), showing a system for radially positioning a scanning head.

Fig. 14 is a geometric representation of two scanning devices having different optical diameters positioned over the center of a phosphor screen, showing "gap time".

Fig. 15 is a illustration of a pair of knife-edge blades for eliminating cross-talk interference between respective scanning heads sequentially traversing across a photostimulable screen.

Fig. 16 is a schematic representation of yet another preferred optical train.

Fig. 17 is a schematic representation of yet another preferred optical train.

Fig. 18 is top plan view of a rotating three-head scanning system positioned over a photostimulable imaging plate.

Fig. 19 is an illustration of a laser beam scanning in an arcuate path across a quadcell.

Fig. 20 shows a system for tracking the angular movement of the scanning heads.

5 Fig. 21 is top plan view corresponding to Fig. 18, showing columns of equal width on the imaging plate.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

10 Overview:

The present invention provides multiple head high-speed rotary scanning devices for reading an image on a phosphor screen and methods for its use. In a first embodiment of the present invention, Figures 1A and 1B show
15 schematic top plan view of preferred aspects of a three-head rotary scanning device 20 according to the present invention as positioned over the surface of phosphor screen 10 and 10a respectively. Rotary scanning device 20 comprises three radially extending optical trains 12 oriented at 120° to one
20 another on its underside. (The positions of optical trains 12 are shown schematically in Figs. 1A and 1B, and the details of optical trains 12a, 12b and 12c are better seen in Figs. 3 through 4C). In a preferred manner of operation, scanning device 20 is rotated about its center 13 in
25 direction R as phosphor screen 10 is moved in direction Y. Rotation of scanning device 20 about center 13 can be accomplished by any conventional high speed motor and drive system that produces a constant speed of rotation of scanning device 20. Alternatively, the speed of rotation of
30 the scanning device can be measured and the data acquisition system can be synchronized to compensate for any minor variations in rotation speed. Translation of phosphor screen 10 in direction Y can be accomplished by attaching phosphor

screen 10 to a motorized transport mechanism, such as a series of rollers and guides, or to a translation stage.

Each of the three optical trains 12 comprise a single scanning head (either 22, 24, or 26) which is
5 disposed at a location at or near the outer perimeter 15 of scanning device 20, as shown. As will be explained, each individual optical train 12 and its associated scanning head, (being either scanning head 22, 24 or 26), operates to direct a focussed beam of incident laser light towards
10 phosphor screen 10 and to receive response radiation emitted by phosphor screen 10. Using any one of a number of optical trains (such as optical trains 12a, 12b, 12c, 12d or 12e as will be described), response radiation received by the scanning head is separated from the incident laser light and
15 is directed towards a centrally-located photomultiplier tube 40 for gathering image data, as will be explained.

In the embodiments shown in Figs. 3 through 4E, each optical train preferably comprises its own laser source 30 such that each scanning head 22, 24 and 26 has its own
20 dedicated laser. By activating each of the three lasers in sequence, each of scanning heads 22, 24 and 26 will sequentially direct laser light onto the surface of phosphor screen 10 while collecting response radiation emitted from phosphor screen 10. By activating each scanning head in
25 sequence, such that only one scanning head is active at a time, or by providing mechanical shielding such that the laser beam in each scanning head reaches the phosphor screen one at a time in sequence, imaging data will be collected from only one scanning head at a time, thereby allowing a
30 single photomultiplier tube to be used for data collection from each of the three optical trains, while preventing stray laser light from adding noise to the collected data signal. Although the present invention operates with one central photomultiplier tube or photodiode, as explained,

the present invention also encompasses embodiments having a dedicated photomultiplier tube or photodiode used for each optical train.

In the three head design shown in Figs. 1A to 4C, 4F, 5 and 12 to 14, each scanning head 22, 24 and 26 will sequentially pass over the surface of phosphor screen 10 in an arcuate path. By advancing the phosphor screen relative to the rotating scanning device, a curved raster scan is generated, which can later be converted from polar coordinates into Cartesian coordinates.

The ratio of optical radius r , (shown in Fig. 1A as the distance from center 13 of scanning device 20 to the focal point of the laser beam under scanning head 22), to one-half the width of the phosphor screen is preferably selected such that the focussed laser beam under each scanning head (22, 24 or 26) passes completely across the entire width of phosphor screen 10 one after another, before a subsequent scanning head passes over the phosphor screen. In a preferred aspect, scanning heads 22, 24 and 26 are operated in sequence, such that only one scanning head is actively scanning across the phosphor screen at a time. For example, the laser in scanning head 22's optical train is turned on during the interval of time during which scanning head 22 moves across the phosphor screen from its position as shown in Fig. 1A to the position presently occupied by scanning head 26 in Fig. 1A. During the interval of time in which scanning head 22 moves across the surface of screen 10, the laser in each of scanning head 24 and 26's optical train will be turned off. After scanning head 22 reaches the position presently occupied by scanning head 26, scanning head 22's laser will be turned off and scanning head 24's laser will be turned on.

Alternatively, the lasers in all three optical trains can be continuously operating, with mechanical

shielding 11 (positioned between phosphor screen 10 and scanner 20 as shown in Fig. 1A), ensuring that the laser beam in each scanning head reaches the phosphor screen one at a time in sequence. Specifically, mechanical shielding
5 can be provided such that the laser beam from any scanning head only reaches screen 10 when the scanning head is passing between the positions occupied by scanning heads 22 and 26 in Fig. 1A. Accordingly, as scanning head 22 moves across screen 10 (to the position presently occupied by
10 scanning head 26), the laser beams emitted from scanning heads 24 and 26 will be blocked from reaching screen 10.

Alternatively, as is shown in Fig. 15, a pair of radially disposed knife edges 250 and 252 may be disposed at an angle of approximately 120° from one another when using a
15 three-head scanning system. Knife edge blades 250 and 252 are preferably fixed to the body frame of the scanner, such that they do not rotate with the scanning disk.

Knife edges 250 and 252 prevent cross-talk interference between sequential scanning heads, when one
20 scanning head is nearing the end of its scan across the phosphor screen and the next scanning head is close to beginning its scan across the screen.

Specifically, as an alternative to dimensioning the scanner diameter to phosphor screen ratio such that a
25 "data time gap" is present, knife edges 250 and 252 can be used to block scanning at the edges of the phosphor screen. As such, each of knife edges 250 and 252 block a scanning head beam a few degrees of rotation prior to the nominal 120° of rotation allotted to each of the three scanning
30 heads. This creates a small angular rotation range in which neither ending nor starting signal beams are passed to the photodetector. Being very close to 120° apart in orientation, knife edges 250 and 252 produce only a very minimal dead time between successive scans. Optionally,

mechanical means may be provided to permit the adjustment of the angle a few degrees less than 120° .

Each of the various scanning heads 22, 24 and 26 will preferably have the same optical radius. Specifically, 5 the optical radius r between center 13 to the focal point of the laser beam under scanning head 22 will equal the optical radius between center 13 and the focal points of laser beams under scanning heads 24 and 26.

Optionally, the ratio of the optical radius 10 relative to the phosphor screen width can also be selected such that a very short time gap occurs between the data collection of each subsequent scanning head. Such a short time gap facilitates image data processing as it makes it easier to distinguish between data collected by each of the 15 various scanning heads 22, 24 or 26 and provides time for initialization of the data acquisition system.

As is shown in Figs. 1A and 1B, scanning device 20 may comprise a disc, however, as is shown in Fig. 12, the rotatable frame of the scanning device may instead comprise 20 a Y-shaped frame 120 having three radially extending arms connected together at the center of the frame.

In a second embodiment, the present invention encompasses a rotating scanning head positioned with a phosphor screen wrapped partially there-around, as is shown 25 in Figs. 9 to 11, employing the optical trains as shown in Figs. 4D and 4E. As is seen in Figs. 9 and 10, phosphor screen 10 is oriented perpendicular to scanning device 20, with phosphor screen 10 wrapped partially around scanning device 20. As seen in Fig. 10, scanning device 20 rotates 30 in direction R with screen 10 advanced in direction Z, being perpendicular to the plane of rotation of scanning device 20. It is to be understood that such relative motion can alternatively be achieved by holding curved phosphor screen 20 at a fixed position and moving scanning device 20 in the

Z direction, rotating scanning device 20 at a fixed Z location and moving phosphor screen 20 in the Z direction, or some combination thereof.

As can be seen in Fig. 9, when using a three head scanner, phosphor screen 10 is preferably wrapped to extend 120 degrees around scanning device 20, such that it spans the arcuate distance between successive scanning heads 22 and 26 as shown. Similarly, when instead using a two head scanner having optical trains spaced 180° apart, phosphor screen 10 is preferably wrapped to extend 180° around scanning device; and similarly, when using a four head scanner, phosphor screen 10 is preferably wrapped to extend 90° around scanning device to ensure that only one scanning head is passing over the surface of the phosphor screen at a time.

Using this arrangement, (as illustrated for a three head scanner in Fig. 9, scanning head 26 will just complete its scan across phosphor screen 10 as scanning head 22 moves into position to scan across phosphor screen 10. An advantage of this embodiment can be seen in Fig. 11 which shows successive scan lines 160, 161 and 162 taken across screen 10 by sequential scanning heads 22, 24 and 26 respectively. As can be seen, scan lines 160, 161 and 162 taken across phosphor screen 10 are quite straight, being deflected by the amount of movement in the Z direction between successive scanning heads 22, 24 and 26 moving across the phosphor screen. (The actual separation distance between successive scan lines 160, 161 and 162 has been exaggerated for illustration purposes).

As can be seen in Fig. 9, should scanning device 20 be dimensioned such that screen 10 does not span all of the distance between successive scan heads, (for example, should screen 10 reach only between points 110 and 111), a gap time will be created between successive scans during the

interval of time in which no scanning head is passing over the phosphor screen, (in particular, during the interval of time a scanning head is passing from points 111 to 112).

5 **The Preferred Optical Trains: .**

The optical trains shown in Figs. 3 to 4C and 4F are preferably for use with the embodiment of the present invention shown in Figs. 1A to 2, 5 and 12 to 14. and the optical trains shown in Figs 4D and 4E are preferably for use with the embodiment of the present invention shown in
10 Figs. 9 to 11, as will be explained.

Referring to the first embodiment, Figure 3 shows a sectional schematic view of a first optical train comprising a laser 30, dichroic mirror 32, reflecting mirror 34, focussing/collimating lens 36, steering mirror 38, and
15 photomultiplier tube 40. In accordance with this embodiment of the invention, laser 30 emits a collimated beam 31 of laser light which is reflected by dichroic mirror 32 towards reflecting mirror 34 and is further reflected downwardly
20 through lens 36 which focuses beam 31 on phosphor screen 10. A response radiation 33 emitted by phosphor screen 10 will travel upwardly through lens 36 which collimates beam 33 and is then reflected by reflecting mirror 34 along with the same optical path as beam 31. When beam 33 reaches dichroic
25 mirror 32, it will pass therethrough eventually reaching steering mirror 38 which reflects beam 33 into photomultiplier tube 40. Optionally, a second focussing lens 37 can be positioned between dichroic mirror 32 and steering mirror 38. The output of photomultiplier tube 40 over time
30 will correspond to the emitted intensity of emissions along an arcuate scan line across phosphor screen 10. For comparison, Figure 4A illustrates a schematic of the optical train 12a layout as seen in Figure 3.

Scanning head 26 comprises those components located at the radially outward end of the optical train. In this embodiment, scanning head 26 comprises reflecting mirror 34 and focussing lens 36. An advantage of this embodiment is that laser 30 and dichroic mirror 32 can be mounted at an inward location proximal the center of the scanning device. Accordingly, a minimal number of system components are disposed at scanning head 26, and thus, the torque required for rotating scanning device 20 at high-speeds is reduced.

Alternative preferred designs for the optical train are possible. For example, Figure 4B shows optical train 12b comprising laser 30 emitting beam 31 radially outward to reflecting mirror 34 which reflects beam 31 through dichroic mirror 32 and focussing lens 36 towards phosphor screen 10. Response radiation emitted by phosphor screen 10 as beam 33 will be reflected by dichroic mirror 32 radially inwardly to steering mirror 38 which in turn reflects beam 33 to photomultiplier tube 40. In this embodiment, scanning head 26 comprises reflecting mirror 34, dichroic mirror 32 and focussing lens 36.

In another preferred aspect, optical train 12c, (shown in Figure 4C), comprises laser 30 which emits beam 31 directly downwardly onto phosphor screen 10. Beam 33 will be reflected by dichroic mirror 32 towards steering mirror 38 which in turn reflects beam 33 into photomultiplier tube 40. In this embodiment, scanning head 26 comprises laser 30, dichroic mirror 32 and focussing lens 36. An advantage of this embodiment of the optical train is that a reflecting mirror, (such as mirror 34), is not required.

Fig. 4F shows an alternative embodiment for the optical train comprising a single laser source 200 with lens 202 which directs a collimated beam towards a mirror 204. Beam 31 is then reflected upwards toward a polyhedral mirror

206, which may preferably comprise a four-sided prism shaped mirror, but may instead comprise three separate triangular shaped mirrors forming a pyramidal shape. Prism mirror 206 is preferably positioned such that three of the prism facets
5 reflect approximately equal fractions of laser beam 31 radially outwards toward each of the three scanning heads 22, 24, and 26. (Only scanning head 22 is shown for ease of illustration).

Outward radially directed beam 31 will be
10 reflected downwardly by mirror 208 toward phosphor screen 10. A response radiation 31 emitted by phosphor screen 10 will travel upwardly reflecting off of mirror 208 and off of dichroic mirror 210 such that response radiation in the form of beam 33 will reach photo multiplier tube 212.

15 Optionally, in any of the above preferred aspects of the optical train, a filter 41, which may comprise a red light blocking filter, may be included, and is preferably positioned between steering mirror 38 and photomultiplier tube 40, as shown in Figs. 4A to 4E. Filter 41 will
20 preferably permit blue wavelength emitted response radiation beam 33 to pass therethrough, yet prohibit the passage of reflected or scattered red wavelength incident laser therethrough. Optionally as well, a collimating lens 35 can be positioned adjacent laser 30 for producing a collimated
25 laser beam, as shown in Figs. 4A to 4F.

An important advantage common to all the above described optical trains 12a, 12b, 12c, 12d, and 12e is the absence of moving parts since the relative movement of each of the scanning heads 22, 24 and 26 over phosphor screen 10
30 is accomplished by rotating scanning device 20 about center 13 and moving phosphor screen 10, (or moving scanning device 20), in direction Y by a transport mechanism. Accordingly, the present invention avoids problems of accurately controlling the position of a scanning head which is

constantly changing speed while moving back and forth in one or more directions.

In the alternative embodiment shown in Figs. 9 to 11, optical trains 12d or 12e (Figs. 4D and 4E) are used. In both optical trains 12d and 12e, the laser beam 31 is directed radially outwardly through focussing lens 36 to phosphor screen 10. In contrast, in optical trains 12a to 12b, (Figs. 4A to 4B), a reflecting mirror 34, is used to reflect the laser beam 31 downwardly 90° toward phosphor screen 10.

An alternative optical train is shown in Fig. 16. In this aspect of the invention, an optical fiber 265 is used. In preferred aspects, fiber waveguide 265 is fabricated from plastic, plastic clad silica (fused quartz) or glass.

In this aspect of the invention, a beam of response radiation emitted by phosphor screen 10 passes through scanning head 22's focusing lens 260 and is then reflected by mirror 262 through fiber input lens 264. After passing through fiber input lens 264, the response radiation beam is directed into distal face 263 optical fiber 265. The beam will be conducted through optical fiber 265, emerging from proximal face 266, thereafter passing through lens 268 such that beam 33 is received by photomultiplier tube 270.

As can be seen, fiber waveguide 265 is curved around a 90° bend, where it turns from the radial to the axial direction. A property of fiber wave guides are that significant bending losses are avoided by assuring that the 90° bend is made with a sufficient radius of curvature for the particular fiber type used.

Lens 268 may preferably be plano-convex shaped to collimate blue light response radiation. Advantages of using fiber waveguides are the elimination of pyramidal or polyhedron shaped mirrors, as was seen in Fig. 4F.

In a preferred aspect, the focal length of the fiber input lens 264 could be slightly longer than that of focusing lens 260 to assure that a sufficient numerical aperture captures and guides all of the signal light.

5 Fig. 17 is a schematic representation of yet another preferred optical train. Optical train 12g comprises a air-clad glass or plastic rod wave guide 300, which is used to conduct signal light from phosphor screen 10 to centrally located photomultiplier tube 320.

10 Light entering into one end of rod 300 will be guided without measurable loss through the rod by the process of total internal reflection. To ensure optimal total internal reflection, the rod's cylindrical surface is made to be optically smooth, clean and only contacted by
15 air. In fact, the only optical signal loss would be due to reflection at rod 300's flat input and output faces at rod ends 302 and 304, respectively. Such losses can be kept below 1% per surface by using appropriate anti-reflection coatings on the rod ends. In preferred aspects, the rod is
20 supported with minimum surface contact. Most preferably, rod ends 302 and 304 are chamfered, resulting in a beveled surface, which is the preferred service for the rod support.

 In preferred aspects, rod 300 will be located within a thin-walled metal tube which would preferably
25 contact rod 300 only at the tube-beveled chamfered surfaces. Rod 300 may be made from glass or plastic. An advantage of wave guide rod 300 is that a substantially smaller central hole is required than would be required to encompass the photomultiplier tube. A mirror 303 and focussing lens 305
30 are also provided.

 In preferred aspects, rod 300 may contain a red attenuating die, such that rod 300 acts as a spectral attenuater of red light. An advantage of such red-light

attenuation by rod 300 is that a low pass interference filter may be omitted from the optical train.

A further advantage of rod 300 which can be seen in Fig. 17 is that the signal can be focussed in plane 315.

5 In a preferred aspect of the invention, each of knife edges 250 and 252 are also disposed in plane 315. As such, rod 330 facilitates distinguishing between the signal received by two different scanning heads when the first scanning head is passing off of one edge of screen 10 while the second
10 scanning head is passing onto another edge of screen 10.

Using any of the various above described embodiments of the optical train, the laser light beam 31 emitted from laser 30 may preferably have a wavelength of about 635 to 680 nm and a power in the range of 0 to 30 mW.
15 Response radiation beam 33 will typically have a wavelength centered at about 390 nm. Focussing/collimating lens 36 may comprise a 5 to 15 mm diameter lens with a focal length of 4 to 10mm which will focus the collimated beam 31 of laser light into a beam width of about 25 to 250 microns, and most
20 preferably 30 to 80 microns on the surface of phosphor screen 10. Minimizing the diameter of the incident laser light beam upon the phosphor screen will minimize destructive pre-reading of the image data caused by forward overlap of the focused beam and reflected and scattered
25 laser light. It is to be understood that the foregoing wavelengths, powers and sizes are merely exemplary and that other wavelengths, powers and sizes may also be used.

The Use of Different Numbers of Equally Spaced Apart

30 Scanning Heads:

The present invention encompasses designs with two, three, four or more scanning heads. The advantages of each of these various designs will be described below.

Using a laser beam excitation system to read an image trapped in a phosphor screen is a "one-time" operation since the actual reading of the stored image by the laser beam will operate to release the image. It is therefore not possible to scan the same pixel of the phosphor screen again and again.

Fig. 5 is an geometric representation of successive scan lines taken by the rotating scanning device 20 of Fig. 1A (not shown) above phosphor screen 10 as screen 10 is incrementally moved in the Y direction. (The actual separation distances between scan lines 150 and 152 are exaggerated in Fig. 5 for illustration purposes.) As the scanning device is rotated, a first arcuate scan line 150 will be taken by a first scanning head passing across the surface of phosphor screen 10 from edge 103 to edge 105. Coincident to the first scanning head reaching edge 105, phosphor screen 10 will have advanced in direction Y by distance D1. Accordingly, a second scan line 152 will then be taken across phosphor screen 10 by a second scanning head passing from edge 103 to 105.

As can be seen, distance D1 is the distance separating scan lines 150 and 152 at center location 104. Distance D2 is the distance separating scan lines 150 and 152 at edge 105, (and also edge 103), as shown. (In particular, distance D2 is measured as the perpendicular distance between lines tangential to scan lines 150 and 152 at edges 105 and 103.) As can be seen, distance D2 is smaller than distance D1 since the separation spacing between lines 150 and 152 will progressively narrow towards the edges of the phosphor screen.

To avoid destructive reading caused by scanning the same pixel in the phosphor screen more than once, it is therefore important that the separation distance D2 between successive scan lines 150 and 152 does not become too small,

and in particular does not become much smaller than the focussed laser beam spot diameter. Should the separation distance D2 become somewhat smaller than the focussed laser beam spot diameter, successive scanning heads will tend to
5 pass over the same pixels at the edges of the phosphor screen, resulting in destructive reading. Accordingly, it is therefore desirable to maintain a sufficient distance D2, which will be defined in part by the diameter of the focussed laser beam. As can be appreciated, the
10 straightness of scan lines 150 and 152 is determined by the ratio of the scanning device optical diameter to phosphor screen width, with straighter scan lines occurring as the ratio of the scanning device optical diameter to phosphor screen width is increased. The larger the spacing of D2
15 becomes at the edges of the phosphor screen, the less potential for destructive reading at the edges of the phosphor screen.

Fig. 6A shows a two head scanning device 50a having scanning heads 52 and 54. Scanning device 50a is
20 dimensioned such that the separation distance between scanning heads 52 and 54 is equal to the width of phosphor screen 10. As scanning device 50a is rotated in direction R, each of scanning heads 52 and 54 will sequentially trace an arcuate semi-circular path across the surface of phosphor
25 screen 10 from edge 108 to edge 106. Scanning heads 52 and 54 are always positioned over the phosphor screen, however, scanning heads 52 and 54 are activated one at a time such that after scanning head 52 has scanned across the phosphor screen from side 108 to 106, (and is then turned off),
30 scanning head 54 will have moved into the position currently occupied by scanning head 52 such that scanning head 54 can be turned on to similarly scan across the phosphor screen from edge 108 to 106.

A major limitation of the system of Fig. 6A is the fact that the reading of the image stored in screen 10 will result in destructive reading of image data proximal the edges of the screen 10 since scanning heads 52 and 54 will
5 tend to pass over the same pixels one after another at screen edges 106 and 108. Specifically, should an attempt be made to acquire a pixel by pixel scan of the phosphor screen using the system as dimensioned in Fig. 6A, it is difficult to generate meaningful data toward screen edges
10 106 and 108, due to the fact that data sampling will essentially comprise oversampling the same pixels with each scan, thereby attempting to re-read pixels from which the stored image has already been released.

As was stated, it would be desirable to have the
15 sequential scan lines passing across the surface of the phosphor screen being as straight as possible, such that adequate separation is maintained between these scan lines at the edges of the screen, (such that individual pixels are not sampled more than once).

20 In the embodiment of the present invention shown in Fig. 6B, the two head scanning device is instead dimensioned with a larger diameter to screen width ratio than as illustrated in Fig. 6A. As such, straighter scan lines, (having greater separation distance therebetween at
25 the edges 108 and 106 of phosphor screen 10), will be generated. However, time gaps will occur between the data sampled by the scanning heads, due to the fact that both scanning heads 52 and 54 will be positioned off the surface of the phosphor screen for some time during each revolution
30 of the scanning device. This problem can be addressed by increasing the rotational speed of the scanner, such that screen 10 can still be scanned in a relatively short period of time. An advantage of the two head scanning system is that only two optical trains need to be built, making the

device easier to manufacture and reducing the weight of the system.

In an alternate embodiment of the invention as shown in Fig. 1A, a three head scanning device is used. The selection of three heads spaced 120 degrees apart coupled to a single central photodetector as shown has a number of advantages. As will be explained, when the optical radius at 1.1547 times one-half the width W_{10} of screen 10, 100% read efficiency can be achieved with successive scanning heads moving across the screen one after another with no duty cycle time lost between successive scanning heads. In particular, a first scanning head will just complete its scan across the screen (and begin to move off the surface of the screen), at the same time that a second scanning head will just commence its scan across the screen (and begin to move onto the surface of the screen). Further advantages of the three head scanning system is that it has a minimal number of separate optical trains, a reasonably small scanning device diameter, at the same time providing sufficiently straight scan path across the surface of the phosphor screen such that sequential scan lines are sufficiently separated at the edges of the phosphor screen such that the diameter of the focussed laser beam does not result in destructive pre-reading.

Fig. 7 shows a four head scanning device 60, having four scanning heads 62, 64, 66 and 68 which are equally spaced at 90° to one another. Scanning device 60 is dimensioned to have a diameter greater than the width of screen 10, as shown, such that sufficiently straight scan lines can be taken as scanning head 62 moves to the position presently occupied by scanning head 68. An advantage of the four head scanner of Fig. 7 is that the system can be dimensioned with the ratio of scanner diameter to screen width set such that successive scan heads move into position

and commence scanning across the screen at the moment in time when the preceding scanning head stops scanning as it passes off the surface of the phosphor screen, as shown.

As can be appreciated, it is possible to add additional numbers of scanning heads. For example, a six head scanning device 70, having six equally spaced apart scanning heads 71, 72, 73, 74, 75, and 76 is shown in Fig. 8. By increasing the optical diameter of the rotary scanning device relative to the width of the phosphor screen, the scan lines are progressively straightened. By adding additional numbers of scanning heads, the advantage of avoiding gaps in data collection is achieved.

Relationship of the Distance from the Center of Each Scanning Head Relative to the Phosphor Screen Width for the Three Head Scanning System:

Returning to the three head system of Fig. 1A, as scanning device 20 is rotated in direction R, scanning heads 22, 24, and 26 will sequentially pass over phosphor screen 10 in generally arcuate paths as has been described. Using the dimensions depicted in Fig. 1A, the optical radius will be 1.1547 times one-half the width W10 of screen 10. The 1.1547 ratio is calculated as follows. Referring to Fig. 1A, the optical radius, (i.e.: the radial distance "r" from center 13 to the focussed laser beam spot on phosphor screen 10 under scanning head 22), will be $1/\sin(60^\circ)$ times $\frac{1}{2}$ W10. Accordingly, the optical diameter of scanning device 20, (which is double the optical radius "r"), will have the same ratio as compared to W10, (which is double $\frac{1}{2}$ W10).

Such a preferred optical diameter to phosphor screen width ratio of 1.1547 can be achieved by using a standard 14 inch width (17 inch length) screen 10 and fabricating scanning device 20 to have an optical diameter of 16.166 inches. It is to be understood, however, that the

three head scanning device of the present invention could be dimensioned to work with other standard phosphor screen sizes, including a 11.547 inch optical diameter scanning device for 10 inch wide by 12 inch long screens and a 9.238
5 inch optical diameter scanning device for 8 inch wide by 10 inch long screens, thereby maintaining the preferred optical diameter to width ratio of 1.1547.

Having a preferred scanning device optical diameter to screen width ratio of 1.1547, as scanning device
10 20 is rotated in direction R, scanning head 22 is activated and will commence scanning across the surface of phosphor screen 10 in an arcuate path until it reaches the position presently shown as occupied by scanning head 26. As
15 scanning head 22 moves off the surface of the phosphor screen, scanning head 24 will be activated as it reaches the position presently shown as occupied by scanning head 22. As can be appreciated, when each of the three scanning heads is sequentially activated as it passes over the surface of phosphor screen 10, image data can be continuously
20 collected, thereby achieving a 100% read efficiency (ie: 100% duty cycle).

In another aspect of the invention, as shown in Figs. 1B and 14, the optical diameter of scanning device 20 is more than 1.1547 times the width W10a of phosphor screen
25 10a. In this embodiment, a short gap of time is provided between the data sampling of each of the three scanning heads, as follows. As scanning device 20 is rotated in direction R, scanning head 22 will commence scanning in an arcuate path across the surface of phosphor screen 10 at the
30 time when it first reaches position 23. In the interval of time during which scanning head 22 moves to position 23, the data acquisition system for scanning head 22 can be initialized. During the interval of time in which scanning head 22 is moving to position 23, scanning head 26 is moved

off the surface of screen 10, and no imaging data will therefore be collected. Such a short interval of time between the operation of successive scanning heads permits one scanning head (eg: scanning head 26) to be shut down while a successive scanning head (eg: scanning head 22) to be activated.

The relationship between the selected scanning device optical diameter to phosphor screen width and its corresponding "gap time" is seen in Fig. 14, which shows two different scanning devices 20a and 20b, having different optical diameters as shown, with scanning devices 20a and 20b centered over phosphor screen 10. Scanning device 20a has an optical diameter to screen width ratio of 1.1547 (as described herein and as illustrated, for example, in Fig. 1A), such that as scanning head 26a passes beyond one edge of the phosphor screen, scanning head 22 is exactly moving into position over the opposite edge of the phosphor screen. Scanning device 20b has an optical diameter to screen width ratio greater than 1.1547, (as described herein and as illustrated, for example, in Fig. 1B). Having such an optical diameter to width ratio, a "gap time" will occur during each duty cycle, (defined herein as 120° of rotation), as each successive scanning head passes through angles ALPHA between points 22b and 23 and between points 27 and 26b.

Scanning Head Alignment:

It is important that each of the various scanning heads 22, 24 and 26 are precisely positioned to be equidistant from the center 13 of scanning device 20, such that each of the scanning heads pass over the exact same path as the scanning device is rotated. Referring to the embodiment shown in Fig. 1A, , a bi-cell 130 can be mounted directly under scanning device 20 at a location in or near

the plane of screen 10. Bi-cell 130 is comprised of a pair of light detectors 131 and 133, separated by a partition 135. As each of scanning heads 22, 24 and 26 is rotated over bi-cell 130, light detectors 131 and 133 will measure incident beam 31 as the scanning head passes over the bi-cell. By moving the radial position of each of the scanning heads passing over bi-cell 130, the incident beams from each of the scanning heads are preferably aligned such that beam 31 passes directly over partition 135 between light detectors 131 and 133, or alternatively, such that the beam 31 is measured in equal strength by light detectors 131 and 133, thereby indicating that beam 31 is passing directly between light detectors 131 and 133. Alternative radial distance position sensing systems are possible. For example, bi-cell 130 can optionally be replaced with a charge couple device (CCD) system.

As is seen in Fig. 13, a positioning system 160 comprising a heating element 161 and a thermal expansion material 163 can be used for radially positioning individual scanning heads, (for example, scanning head 26), by moving mirror 34 radially. Specifically, the application of a current through heating element 161 will cause expansion of thermal expansion material 163, which in turn will cause the scanning head to be moved radially. By varying the current applied to heating element 161, it is therefore possible to move scanning head radially inwardly and outwardly. Alternatively, each of the scanning heads could be set manually inwardly and outwardly by set screws or other fasteners.

It is to be understood that in the various designs of the present invention, the radial positioning system used will preferably move all components of the optical system disposed adjacent the outer perimeter of the rotating scanning device. Accordingly, in various designs, the

positioning system may move a reflecting mirror, a dichroic mirror and a laser source, as required.

In the system shown in Figs. 9 and 10, proper alignment of the scanning heads in the Z direction can
5 similarly be accomplished with a bi-cell 230, comprised of a pair of light detectors 231 and 233, separated by a partition 235, (operating the same way as was described with respect to bi-cell 130).

10 **Systems for Converting a Radial Coordinate Pixel Scan into a Rectangular Coordinate Pixel Scan:**

Referring to Fig. 18, an imaging plate 110 which may preferably comprise a photostimulable phosphor image storage screen is positioned beneath a rotating disc-shaped
15 scanner 112. Scanner 112 has three scanning heads 122, 124, and 126, disposed at its outer perimeter as shown. Preferably, phosphor screen 110 is moved in direction Y relative to rotating scanner 112.

Scanner 112 is rotated in direction R such that
20 scanning heads 122, 126, and 124, each trace sequential arcuate paths across phosphor screen 110. Scanning heads 122, 124, and 126, preferably direct a focused laser beam downwardly onto screen 110, and a response radiation emitted by screen 110 is received back along the same
25 optical path through each of scanning heads 122, 124, and 126. The response radiation so received by the various scanning heads is used to read the image stored in the phosphor screen 110.

Passing in arcuate paths over the surface of
30 phosphor screen 110, each of scanning heads 122, 124, and 126, can be used to perform a pixel-by-pixel scan which will initially be in a radial coordinate system. The present invention provides systems for converting such a radial coordinate pixel scan into a rectangular coordinate pixel

scan such as would be generated by a standard raster scan. An advantage of the present invention is that its resulting rectangular coordinate pixel scan can be rendered into an image more efficiently by the system's computer.

5 When performing a pixel-by-pixel scan, it is essential to know where each of the scanning heads are positioned with respect to the phosphor screen 110 at all moments in time. In accordance with the present invention, the position of each scanning head is determined as the
10 scanning head passes over a sensor. In accordance with the present invention, only one sensor is used to determine the position of each of the three scanning heads, as follows.

Each of scanning heads 122, 126, and 124, are preferably operated one at a time such that only one
15 scanning head is actively scanning in an arcuate path across screen 110 from edge 111 to edge 113. In addition, the relative diameter of scanner 112 with respect to the width of screen 110 is preferably constructed such that as one scanning head reaches edge 111, the previous scanning head
20 departs edge 113. Specifically, by way of example, scanning head 122 will reach point 115 at or immediately after scanning head 124 reaches point 117. Accordingly, only one scanning head is generating a signal at a time. (Scanning head 126 is inactive as it moves between edge 113 and edge
25 111.)

In a preferred aspect of the invention, the sensor which determines the position of each scanning head comprises a quadcell 130 which is positioned adjacent edge 111 of screen 110 as shown in Fig. 18. As shown in
30 Fig. 19, quadcell 130 preferably comprises four separate photodetection elements A, B, C, and D. A laser spot 140 (which will be directed downwardly from each of scanning heads 122, 126, and 124, in sequence), will move across quadcell in arcuate path P.

Photodetectors A, B, C, and D, can be used to determine path P by determining where and when the center of laser beam spot 140 passes across zero crossing 131 at point 132 and zero crossing 133 at point 134. Specifically, when the center of laser beam spot 140 reaches point 132, the combined output of photodetectors A and B will equal the combined output of photodetectors B and D. Similarly, when the center of laser beam spot 140 reaches zero crossing 133, the combined output of photodetectors A and B will equal the combined output of photodetectors C and D. Accordingly, by measuring the separate outputs of photodetectors A, B, C and D, it is possible to precisely determine the coordinates of points 132 and 134. Knowing points 132 and 134, and determining the radial distance from scanner center 125 to each of points 132 and 134, it is possible to precisely determine path P.

Further advantages of quadcell 130 include its ability to measure the intensity of laser beam spot 140 by determining the summation of the outputs of all of respective photodetectors A, B, C, and D. Moreover, by determining the relative outputs of the various photodetectors A, B, C and D over time, (thereby determining when portions of laser beam spot 140 are disposed on each side of zero crossings 131 and 133 at various points in time), it is also possible to determine a gaussian profile of laser beam spot 140. In addition, by determining the interval of time between which laser beam spot 140 moves from point 132 to point 134, it is possible to determine the speed of angular rotation of scanner 112.

A further advantage of quadcell 130 is that it is possible to determine the radial distance between each of points 132 and 134 and disc center 125 for each of the various scanning heads. Determining this distance is important, as each of scanning heads 22, 24, and 26 may be

disposed at slightly different radial distances from scanner center 25. Moreover, the laser beams directed downwardly by each of scanning heads 122, 124, and 126 may be somewhat offset from one another in terms of their radial distance from center 125. Accordingly, by determining points 132 and 134 for each of the laser beam spots emitted by each of the various scanning heads 122, 124, and 126, the path P taken by each of the scanning heads across screen 110 can be determined. A look-up table may be used in conjunction with the quadcell to determine the angular position of each of the respective scanning heads.

It is also important to determine the precise angular position of laser beam spot 140 as it moves across the surface of screen 110 in an angular path P. Accordingly, in another aspect of the present invention, the angular movement of scanning head 112 is continuously tracked. It is specifically important to track the movement of the active scanning head as it moves across screen 110 such that small speed changes in the rotation of scanner 112 can be compensated for as scanner 112 spins in direction R. In a preferred aspect of the invention, the speed at which disc 112 is rotating is constantly measured such that the exact positions of the active scanning head (either 122, 126, or 124) scanning across the screen can be known at all times.

Referring to Fig. 20, an encoder 180 having a gradient strip 182 disposed thereon is provided at a central location about center 125. Encoder 180 spins together with scanning disc 112. By determining the position of a gradient strip 182 it is possible to determine the exact angular position of each of the scanning heads 122, 124, and 126, as follows. Gradient strip 182 preferably comprises a plurality of equally spaced-apart tick marks which can be identified by sensors 190, 192, and 194. In a preferred

aspect, gradient strip 182 has a length spanning between successive sensors 190, 192, and 194. By counting the number of tick marks that have passed respective sensors 190, 192 and 194 over time, it is possible to track the angular movement of scanner 112 over time. An advantage of having gradient strip 182 wrap only partially around encoder 180 is that each of respective sensors 190, 192 and 194 will detect the starting point and the ending point of the strip.

When scanning in an arcuate path over a rectangular pixel array, it is also important to perform the scan in a way which does not oversample the pixels in certain regions of the screen and undersample the pixels in other regions of the screen. Accordingly, in another aspect of the invention, the rate of pixel sampling is adjusted as the scanning head (122, 126 or 124) moves across screen 110 from edge 111 to edge 113.

Fig. 21 illustrates a plurality of columns 151, 152, 153, 154, etc. (shown up to no. 164) which have equal widths in order to conceptually represent a plurality of pixels P1, P2, P3, through to P15, etc. on screen 110. As can be seen, when moving along path P, pixels P1 and P2 are the farthest apart in the pixel sequence and pixels P14 and P15 are the closest together. Accordingly, when scanning laser beam spot 140 over screen 10, it is preferable to have a longer interval of time between the sampling of successive pixels P1 and P2 than between the sampling of successive pixels P14 and P15. Specifically, in accordance with the present invention, the pixel sampling rate is preferably increased as the scanning head moves across the center of screen 110 (i.e., in the range of pixels 114 and 115). Conversely, the pixel sampling rate is preferably decreased as the scanning head moves between pixels disposed at edges 111 and 113 of the screen, (i.e., pixels P1 and P2). By decreasing the pixel sampling rate towards edges 111 and

113 of screen 110, this compensates for what otherwise would result in a greater sampling density adjacent these edges 111 and 113.

WHAT IS CLAIMED IS:

- 1 1. A three-head scanning device for reading an
2 image stored on a photostimulable medium, comprising,
3 a rotatable frame having a center and an outer
4 perimeter;
5 at least one photomultiplier tube mounted to the
6 rotatable frame at a location proximal the center of the
7 rotatable frame;
8 three radially extending optical trains mounted to
9 the rotatable frame at 120 degrees to one another, each
10 optical train configured to direct incident laser light
11 towards the photostimulable medium and to direct response
12 radiation emitted by the photostimulable medium in response
13 to the incident laser light towards the photomultiplier
14 tube.
- 1 2. The three-head scanning device of claim 1,
2 wherein, each optical train comprises:
3 (i) a laser mounted to the rotatable frame at
4 a location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 generally normal to a direction radially outwards from the
7 center of the rotatable frame;
8 (ii) a dichroic mirror mounted to the
9 rotatable frame at a location adjacent the laser, the
10 dichroic mirror positioned to reflect the incident laser
11 light emitted by the laser in the direction radially
12 outwards from the center of the rotatable frame;
13 (iii) a reflecting mirror mounted to the
14 rotatable frame at a location proximal the outer perimeter
15 of the rotatable frame, wherein the reflecting mirror is
16 positioned to reflect the incident laser light in the



* C L M S *

17 direction generally normal to the direction radially
18 outwards from the center of the rotatable frame;

19 (iv) a steering mirror mounted to the
20 rotatable frame at a location adjacent the photomultiplier
21 tube, the steering mirror being positioned to reflect the
22 response radiation into the photomultiplier tube; and

23 (v) a focusing lens between the reflecting
24 mirror and the photostimulable medium to focus the incident
25 laser light on the photostimulable medium and to collimate
26 response radiation emitted by the photostimulable medium.

1 3. The three-head scanning device of claim 2,
2 further comprising:

3 a positioning system for moving the reflecting
4 mirror and the focussing lens back and forth in a radial
5 direction.

1 4. The three-head scanning device of claim 1,
2 wherein, each optical train comprises:

3 (i.) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 radially outwards from the center of the rotatable frame;

7 (ii) a reflecting mirror mounted to the rotatable
8 frame at a location proximal the outer perimeter of the
9 rotatable frame, wherein the reflecting mirror is positioned
10 to reflect the incident laser light in a direction generally
11 normal to the direction radially outwards from the center of
12 the rotatable frame;

13 (iii) a dichroic mirror mounted to the rotatable
14 frame at a location proximal the outer perimeter of the
15 rotatable frame, the dichroic mirror positioned to reflect
16 the response radiation in a direction radially inwards to
17 the center of the rotatable frame;

18 (iv) a steering mirror mounted to the rotatable
19 frame at a location adjacent the photomultiplier tube, the



20 steering mirror being positioned to reflect the response
21 radiation into the photomultiplier tube; and
22 (v) a focusing lens between the reflecting mirror
23 and the photostimulable medium to focus the incident laser
24 light on the photostimulable medium and to collimate
25 response radiation emitted by the photostimulable medium.

1 5. The three-head scanning device of claim 4,
2 further comprising:

3 a positioning system for moving the reflecting
4 mirror, the dichroic mirror and the focussing lens back and
5 forth in a radial direction.

1 6. The three-head scanning device of claim 1,
2 wherein, each optical train comprises:

3 (i.) a laser mounted to the rotatable frame at a
4 location proximal the outer perimeter of the rotatable
5 frame, the laser emitting the incident laser light in a
6 direction generally normal to the rotatable frame;

7 (ii) a dichroic mirror mounted to the rotatable
8 frame at a location proximal the laser, the dichroic mirror
9 positioned to reflect the response radiation in a direction
10 radially inwards to the center of the rotatable frame; and

11 (iii) a steering mirror mounted to the rotatable
12 frame at a location adjacent the photomultiplier tube, the
13 steering mirror being positioned to reflect the response
14 radiation into the photomultiplier tube; and

15 (iv) a focusing lens between the reflecting mirror
16 and the photostimulable medium to focus the incident laser
17 light on the photostimulable medium and to collimate
18 response radiation emitted by the photostimulable medium.

1 7. The three-head scanning device of claim 6,
2 further comprising:

3 a positioning system for moving the laser, the
4 dichroic mirror and the focussing lens back and forth in a
5 radial direction.



1 8. The three-head scanning device of claim 1,
2 wherein, each optical train comprises:

3 (i.) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 generally normal to a direction radially outwards from the
7 center of the rotatable frame;

8 (ii) a dichroic mirror mounted to the rotatable
9 frame at a location adjacent the laser, the dichroic mirror
10 positioned to reflect the incident laser light emitted by
11 the laser in the direction radially outwards from the center
12 of the rotatable frame;

13 (iii) a steering mirror mounted to the rotatable
14 frame at a location adjacent the photomultiplier tube, the
15 steering mirror being positioned to reflect the response
16 radiation into the photomultiplier tube; and

17 (iv) a focusing lens between the dichroic mirror
18 and the photostimulable medium to focus the incident laser
19 light on the photostimulable medium and to collimate
20 response radiation emitted by the photostimulable medium.

1 9. The three-head scanning device of claim 8,
2 further comprising:

3 a positioning system for moving the dichroic
4 mirror and the focussing lens up and down in an axial
5 direction.

1 10. The three-head scanning device of claim 1,
2 wherein, each optical train comprises:

3 (i.) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 radially outwards from the center of the rotatable frame;

7 (ii) a dichroic mirror mounted to the rotatable
8 frame at a location proximal the outer perimeter of the
9 rotatable frame, the dichroic mirror positioned to reflect



10 the response radiation in a direction generally normal to
11 the direction radially outwards from the center of the
12 rotatable frame;
13 (iii) a reflecting mirror mounted to the rotatable
14 frame at a location proximal the outer perimeter of the
15 rotatable frame, wherein the reflecting mirror is positioned
16 to reflect the response radiation in a direction radially
17 inwards to the center of the rotatable frame;
18 (iv) a steering mirror mounted to the rotatable
19 frame at a location adjacent the photomultiplier tube, the
20 steering mirror being positioned to reflect the response
21 radiation into the photomultiplier tube; and
22 (v) a focusing lens between the dichroic mirror
23 and the photostimulable medium to focus the incident laser
24 light on the photostimulable medium and to collimate
25 response radiation emitted by the photostimulable medium.

1 11. The three-head scanning device of claim 10,
2 further comprising:
3 a positioning system for moving the laser, the
4 dichroic mirror and the focussing lens up and down in an
5 axial direction.

1 12. The three-head scanning device of claim 1,
2 wherein,
3 the three lasers are mounted to the rotatable
4 frame at locations proximal the outer perimeter of the
5 rotatable frame.

1 13. The three-head scanning device of claim 1,
2 wherein,
3 the three lasers are mounted to the rotatable
4 frame at locations proximal the center of the rotatable
5 frame.



1 14. The three-head scanning device of claim 1,
2 further comprising,
3 three steering mirrors mounted to the rotatable
4 frame at a location adjacent the photomultiplier tube, the
5 steering mirrors each configured to direct the response
6 radiation into the photomultiplier tube.

1 15. The three-head scanning device of claim 1,
2 further comprising,
3 at least one red wavelength blocking filter
4 positioned between the photomultiplier tube and each
5 dichroic mirror.

1 16. The three-head scanning device of claim 1,
2 wherein,
3 the rotatable frame comprises a disc.

1 17. The three-head scanning device of claim 1,
2 wherein,
3 the rotatable frame comprises a Y-shaped frame
4 having three radially extending arms attached together at
5 the center of the frame.

1 18. The three-head scanning device of claim 1,
2 wherein,
3 the focussing lens focuses a laser beam to a
4 diameter of 25 to 250 microns.

1 19. The three-head scanning device of claim 18,
2 wherein,
3 the focussing lens focuses a laser beam to a
4 diameter of about 50 to 80 microns.

1 20. The three-head scanning device of claim 1,
2 further comprising:
3 mechanical shielding extending across a portion of
4 the three-head scanning device, the mechanical shielding
5 dimensioned to permit the incident laser light from only one



6 of the three lasers to reach the photostimulatable medium at
7 a time.

1 21. A system for reading an image stored on a
2 photostimulatable medium, comprising, in combination:
3 a photostimulatable medium, and
4 a three-head scanning device comprising:
5 a rotatable frame having a center and an
6 outer perimeter;
7 a photomultiplier tube mounted to the
8 rotatable frame at a location proximal the center of the
9 rotatable frame,
10 three lasers mounted to the rotatable frame,
11 wherein each of the three lasers are mounted equidistant
12 from the center of the rotatable frame and equidistant from
13 one another;
14 three dichroic mirrors mounted to the
15 rotatable frame, wherein each of the three dichroic mirrors
16 are mounted equidistant from the center of the rotatable
17 frame and equidistant from one another, each dichroic mirror
18 directing laser light from one of the three lasers towards
19 the photostimulatable medium and each dichroic mirror
20 directing response radiation from the photostimulatable medium
21 radially inwards towards the photomultiplier tube; and
22 three focusing lenses, each mounted between a
23 reflecting mirror and the photostimulatable medium to focus
24 the incident laser light on the photostimulatable medium and
25 to collimate response radiation emitted by the
26 photostimulatable medium.

1 22. The system of claim 21, wherein,
2 the three lasers are mounted to the rotatable
3 frame at locations proximal the center of the rotatable
4 frame, and
5 the three dichroic mirrors are mounted to the
6 rotatable frame at locations proximal the center of the
7 rotatable frame.



1 23. The system of claim 22, further comprising:
2 three reflecting mirrors mounted to the rotatable
3 frame at locations equidistant from the center of the
4 rotatable frame and equidistant from one another, the three
5 reflecting mirrors each configured to reflect the incident
6 laser light towards the photostimulable medium and to
7 reflect the response radiation emitted by the
8 photostimulable medium in response to the incident laser
9 light radially inwards towards the photomultiplier tube.

1 24. The system of claim 21, wherein,
2 the three lasers are mounted to the rotatable
3 frame at locations proximal the center of the rotatable
4 frame, and
5 the three dichroic mirrors are mounted to the
6 rotatable frame at locations proximal the outer perimeter of
7 the rotatable frame.

1 25. The system of claim 24, further comprising:
2 three reflecting mirrors mounted to the rotatable
3 frame at locations equidistant from the center of the
4 rotatable frame and equidistant from one another, the three
5 reflecting mirrors each configured to reflect the incident
6 laser light towards the photostimulable medium.

1 26. The system of claim 24, further comprising:
2 three reflecting mirrors mounted to the rotatable
3 frame at locations equidistant from the center of the
4 rotatable frame and equidistant from one another, the three
5 reflecting mirrors each configured to reflect the response
6 radiation emitted by the photostimulable medium in response
7 to the incident laser light radially inwards towards the
8 photomultiplier tube.



1 27. The system of claim 21, wherein,
2 the three lasers are mounted to the rotatable
3 frame at locations proximal the outer perimeter of the
4 rotatable frame, and
5 the three dichroic mirrors are mounted to the
6 rotatable frame at locations proximal the outer perimeter of
7 the rotatable frame.

1 28. The system as in claim 21, wherein,
2 the scanning rotatable frame has an optical
3 diameter of at least 1.1547 times the width of the
4 photostimulable medium.

1 29. The system of claim 21, further comprising,
2 a transport mechanism for moving the
3 photostimulable medium in one direction.

1 30. The system of claim 22, further comprising,
2 a positioning system for adjusting the position of
3 the dichroic mirror in a radial direction, comprising:
4 a heating element mounted to a thermal
5 expansion material, the thermal expansion material mounted
6 to the dichroic mirror such that the expansion of the
7 thermal expansion material causes the dichroic mirror to
8 move in a radial direction.

1 31. The system of claim 23, further comprising,
2 a positioning system for adjusting the position of
3 the reflecting mirror in a radial direction, comprising:
4 a heating element mounted to a thermal
5 expansion material, the thermal expansion material mounted
6 to the reflecting mirror such that the expansion of the
7 thermal expansion material causes the reflecting mirror to
8 move in a radial direction.



1 32. The system of claims 30 or 31, further
2 comprising:

3 a bi-cell mounted adjacent the rotatable frame at
4 a location at the perimeter of the rotating frame, the bi-
5 cell comprising a pair of light detectors for determining
6 the optical radius of each of the successive scanning heads
7 by determining the radial distance from the center of the
8 rotating frame to a focussed laser spot under each of the
9 scanning heads.

1 33. The system of claims 30 or 31, further
2 comprising:

3 a CCD mounted under the rotatable frame at a
4 location at the perimeter of the rotating frame for
5 determining the optical radius of each of the successive
6 scanning heads by determining the radial distance from the
7 center of the rotating frame to a focussed laser spot under
8 each of the scanning heads.

1 34. A method of reading an image stored on a
2 photostimulable medium, comprising:

3 rotating a three-head scanning device over the
4 surface of the photostimulable medium, the three-head
5 scanning device comprising three equidistantly spaced-apart
6 scanning heads disposed about a common center at angles of
7 120 degrees to one another, such that each scanning head
8 successively traces an path across the surface of the
9 photostimulable medium, wherein each scanning head is
10 configured to direct incident laser light from a laser
11 source towards the photostimulable medium and to direct
12 response radiation emitted by the photostimulable medium
13 towards a photomultiplier tube disposed at the common
14 center;

15 activating each of the scanning heads by emitting
16 incident laser light from a laser source dedicated to the
17 scanning head;



18 measuring the response radiation emitted by the
19 photostimulable medium with the photomultiplier tube,
20 thereby gathering image data in polar coordinate form; and
21 advancing the photostimulable medium in a first
22 direction.

1 35. The method of claim 34, wherein, each of the
2 three scanning heads is activated in sequence such that only
3 one scanning head is gathering image data at a time.

1 36. The method of claim 34, wherein, the
2 photostimulable medium is advanced in incremental steps in
3 the first direction.

1 37. The method of claim 34, wherein, the
2 photostimulable medium is advanced continuously in the first
3 direction.

1 38. The method of claim 34, further comprising:
2 transforming the image data from polar coordinate
3 form into Cartesian form, thereby generating a straight-line
4 X-Y raster scan of the photostimulable medium.

1 39. The method of claim 34, further comprising:
2 dimensioning the optical diameter of the three-
3 head scanning device to be at least 1.1547 times the width
4 of the photostimulable medium.

1 40. The method of claim 34, wherein,
2 the photostimulable medium is planar and is
3 disposed parallel to a plane defined by the three
4 equidistantly spaced apart scanning heads.

1 41. The method of claim 40, wherein,
2 the first direction is parallel to the plane
3 defined by the three equidistantly spaced apart scanning
4 heads.



1 42. The method of claim 34, wherein,
2 the photostimulable medium is wrapped partially
3 around the perimeter of the scanning device, and the first
4 direction is perpendicular to a plane defined by the three
5 equidistantly spaced apart scanning heads.

1 43. The method of claim 41, wherein,
2 the photostimulable medium is wrapped not more
3 than 120° around the perimeter of the scanning device.

1 44. A multiple-head scanning device for reading
2 an image stored on a photostimulable medium, comprising,
3 a rotatable frame having a center and an outer
4 perimeter;
5 at least one photomultiplier tube mounted to the
6 rotatable frame at a location proximal the center of the
7 rotatable frame; and
8 a plurality of radially extending optical trains
9 mounted to the rotatable frame, each optical train
10 configured to direct incident laser light towards the
11 photostimulable medium and to direct response radiation
12 emitted by the photostimulable medium in response to the
13 incident laser light towards the photomultiplier tube.

1 45. The multiple-head scanning device of claim
2 44, wherein, each optical train comprises:
3 (i.) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 generally normal to a direction radially outwards from the
7 center of the rotatable frame;
8 (ii) a dichroic mirror mounted to the rotatable
9 frame at a location adjacent the laser, the dichroic mirror
10 positioned to reflect the incident laser light emitted by
11 the laser in the direction radially outwards from the center
12 of the rotatable frame;



13 (iii) a reflecting mirror mounted to the rotatable
14 frame at a location proximal the outer perimeter of the
15 rotatable frame, wherein the reflecting mirror is positioned
16 to reflect the incident laser light in the direction
17 generally normal to the direction radially outwards from the
18 center of the rotatable frame;

19 (iv) a steering mirror mounted to the rotatable
20 frame at a location adjacent the photomultiplier tube, the
21 steering mirror being positioned to reflect the response
22 radiation into the photomultiplier tube; and

23 (v) a focusing lens between the reflecting mirror
24 and the photostimulable medium to focus the incident laser
25 light on the photostimulable medium and to collimate
26 response radiation emitted by the photostimulable medium.

1 46. The multiple-head scanning device of claim
2 44, wherein, each optical train comprises:

3 (i) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 radially outwards from the center of the rotatable frame;

7 (ii) a reflecting mirror mounted to the rotatable
8 frame at a location proximal the outer perimeter of the
9 rotatable frame, wherein the reflecting mirror is positioned
10 to reflect the incident laser light in a direction generally
11 normal to the direction radially outwards from the center of
12 the rotatable frame;

13 (iii) a dichroic mirror mounted to the rotatable
14 frame at a location proximal the outer perimeter of the
15 rotatable frame, the dichroic mirror positioned to reflect
16 the response radiation in a direction radially inwards to
17 the center of the rotatable frame;

18 (iv) a steering mirror mounted to the rotatable
19 frame at a location adjacent the photomultiplier tube, the
20 steering mirror being positioned to reflect the response
21 radiation into the photomultiplier tube; and



22 (v) a focusing lens between the reflecting mirror
23 and the photostimulable medium to focus the incident laser
24 light on the photostimulable medium and to collimate
25 response radiation emitted by the photostimulable medium.

1 47. The multiple-head scanning device of claim
2 44, wherein, each optical train comprises:

3 (i) a laser mounted to the rotatable frame at a
4 location proximal the outer perimeter of the rotatable
5 frame, the laser emitting the incident laser light in a
6 direction generally normal to the rotatable frame;

7 (ii) a dichroic mirror mounted to the rotatable
8 frame at a location proximal the laser, the dichroic mirror
9 positioned to reflect the response radiation in a direction
10 radially inwards to the center of the rotatable frame; and

11 (iii) a steering mirror mounted to the rotatable
12 frame at a location adjacent the photomultiplier tube, the
13 steering mirror being positioned to reflect the response
14 radiation into the photomultiplier tube; and

15 (iv) a focusing lens between the reflecting mirror
16 and the photostimulable medium to focus the incident laser
17 light on the photostimulable medium and to collimate
18 response radiation emitted by the photostimulable medium.

1 48. The multiple-head scanning device of claim
2 44, wherein, each optical train comprises:

3 (i) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 generally normal to a direction radially outwards from the
7 center of the rotatable frame;

8 (ii) a dichroic mirror mounted to the rotatable
9 frame at a location adjacent the laser, the dichroic mirror
10 positioned to reflect the incident laser light emitted by
11 the laser in the direction radially outwards from the center
12 of the rotatable frame;



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13 (iii) a steering mirror mounted to the rotatable
14 frame at a location adjacent the photomultiplier tube, the
15 steering mirror being positioned to reflect the response
16 radiation into the photomultiplier tube; and

17 (iv) a focusing lens between the dichroic mirror
18 and the photostimulable medium to focus the incident laser
19 light on the photostimulable medium and to collimate
20 response radiation emitted by the photostimulable medium.

1 49. The multiple-head scanning device of claim
2 44, wherein, each optical train comprises:

3 (i) a laser mounted to the rotatable frame at a
4 location proximal the center of the rotatable frame, the
5 laser emitting the incident laser light in a direction
6 radially outwards from the center of the rotatable frame;

7 (ii) a dichroic mirror mounted to the rotatable
8 frame at a location proximal the outer perimeter of the
9 rotatable frame, the dichroic mirror positioned to reflect
10 the response radiation in a direction generally normal to
11 the direction radially outwards from the center of the
12 rotatable frame;

13 (iii) a reflecting mirror mounted to the rotatable
14 frame at a location proximal the outer perimeter of the
15 rotatable frame, wherein the reflecting mirror is positioned
16 to reflect the response radiation in a direction radially
17 inwards to the center of the rotatable frame;

18 (iv) a steering mirror mounted to the rotatable
19 frame at a location adjacent the photomultiplier tube, the
20 steering mirror being positioned to reflect the response
21 radiation into the photomultiplier tube; and

22 (v) a focusing lens between the dichroic mirror
23 and the photostimulable medium to focus the incident laser
24 light on the photostimulable medium and to collimate
25 response radiation emitted by the photostimulable medium.

1 50. A method of reading an image stored on a
2 photostimulable medium, comprising:



3 rotating a multiple-head scanning device over the
4 surface of the photostimulable medium, the multiple-head
5 scanning device comprising a plurality of radially extending
6 optical trains each having a scanning head disposed proximal
7 an outer perimeter of the scanning device, such that each
8 scanning head successively traces an path across the surface
9 of the photostimulable medium, wherein each scanning head is
10 configured to direct incident laser light from a laser
11 source towards the photostimulable medium and to direct
12 response radiation emitted by the photostimulable medium
13 towards a photomultiplier tube disposed at the common
14 center;

15 activating each of the scanning heads by emitting
16 incident laser light from a laser source dedicated to the
17 scanning head;

18 measuring the response radiation emitted by the
19 photostimulable medium with the photomultiplier tube,
20 thereby gathering image data in polar coordinate form; and

21 advancing the photostimulable medium in a first
22 direction.

1 51. The method of claim 50, wherein, each of the
2 scanning heads is activated in sequence such that only one
3 scanning head is gathering image data at a time.

1 52. The method of claim 50, wherein, each of the
2 laser sources are operated continuously and mechanical
3 shielding is provided such that only one scanning head is
4 gathering image data at a time.

1 53. The method of claim 50, further comprising:
2 transforming the image data from polar coordinate
3 form into Cartesian form, thereby generating a straight-line
4 X-Y raster scan of the photostimulable medium.



1 54. The method of claim 50, wherein, the
2 photostimulable medium is planar and is disposed parallel to
3 a plane defined by the scanning heads.

1 55. The method of claim 54, wherein,
2 the first direction is parallel to the plane
3 defined by the scanning heads.

1 56. The method of claim 50, wherein,
2 the photostimulable medium is wrapped partially
3 around the perimeter of the scanning device, and the first
4 direction is perpendicular to a plane defined by the
5 scanning heads.

1 57. The multiple head scanning device of claim
2 44, wherein, each optical train comprises:
3 (i) a laser emitting incident laser light;
4 (ii) a first reflecting mirror mounted to the
5 rotatable frame at a location proximal to the center of the
6 rotatable frame;
7 (iii) a polyhedral prism reflecting surface for
8 splitting the incident laser light into radially outward
9 directions from the center of the rotatable frame;
10 (iv) a dichroic mirror passing the incident beam
11 radially outwards therethrough; and
12 (v) for reflecting a response radiation toward
13 the photomultiplier tube.

1 58. The multi-head scanning device of claim 44,
2 further comprising:
3 a laser;
4 a polyhedral mirror mounted to the rotatable frame
5 at a location proximal the center of the center of the
6 rotatable frame, the polyhedral mirror reflecting
7 approximately equal fractions of the incident laser light
8 radially outwardly from the center of the rotatable frame.



1 59. The multi-head scanning device of claim 58,
2 wherein the polyhedral mirror is a four-sided prism.

1 60. The multi-head scanning device of claim 58,
2 wherein the polyhedral mirror comprises three separate
3 triangular shaped mirrors forming a pyramidal shape.

1 61. The multi-head scanning device of claim 58, .
2 wherein the polyhedral mirror has a number of facets equal
3 to one plus the number of radially extending optical trains.

1 62. The scanning device of claim 1 or 44, further
2 comprising:

3 a scanner body supporting the rotatable frame; and
4 a pair of blocking structures mounted to the
5 scanner body such that the blocking structures do not rotate
6 with the frame, the blocking structures being disposed at an
7 angle to one another, wherein the angle is slightly less
8 than $360^\circ/n$ where n is the number of radially extending
9 optical trains.

1 63. The scanning device of claim 62, wherein, the
2 blocking structures comprise knife edge blades.

1 64. The scanning device of claim 1 or 44, wherein
2 each of the radially extending optical trains further
3 comprises:

4 an optical fiber wave guide positioned to conduct
5 an optical signal between the photomultiplier tube and the
6 photostimulable medium.

1 65. The scanning device of claim 44, further
2 comprising:

3 an air-clad rod wave guide positioned to conduct
4 an optical signal between the photomultiplier tube and the
5 photostimulable medium.



1 66. The scanning device of claim 65, wherein the
2 air-clad rod wave guide comprises an attenuating dye.

1 67. A method for converting a radial coordinate
2 pixel scan into a rectangular coordinate pixel scan,
3 comprising:
4 rotating a scanner having a scanning head attached
5 thereto such that the scanning head passes in an angular
6 path across a photostimulable medium;
7 determining the position of the scanning head as
8 the scanning head passes over a sensor;
9 tracking the angular movement of the scanning head
10 across the photostimulable medium; and
11 adjusting a pixel sampling rate as the scanning
12 head moves across a photostimulable medium.

1 68. The method of claim 67, wherein rotating a
2 scanner having a scanning head attached thereto such that
3 the scanning head passes in an angular path across a
4 photostimulable medium, comprises:
5 rotating a disc-shaped scanner having three
6 scanning heads disposed thereon, wherein the three scanning
7 heads are disposed 120° apart at the perimeter of the
8 scanner, such that each of the three scanning heads
9 sequentially follow one another across the photostimulable
10 medium.

1 69. The method of claim 67, wherein the sensor
2 comprises a quadcell.

1 70. The method of claim 69, wherein determining
2 the position of the scanning head as the scanning head
3 passes over a sensor, comprises:
4 passing the scanning head over the quadcell; and
5 determining a first coordinate position of the
6 center of a laser beam emitted by the scanning head, as the



7 center of the laser beam passes over a first zero crossing
8 of the quadcell.

1 71. The method of claim 70, further comprising:
2 determining a second coordinate position of the
3 center of a laser beam emitted by the scanning head, as the
4 center of the laser beam passes over a second zero crossing
5 of the quadcell.

1 72. The method of claim 71, further comprising;
2 determining the speed of movement of the scanning
3 head by determining the interval of time between the moments
4 when the scanning head passes over the first and second zero
5 crossings.

1 73. The method of claim 69, further comprising:
2 measuring the intensity of a laser beam with the
3 quadcell, the laser beam being emitted by the scanning head.

1 74. The method of claim 69, further comprising:
2 determining the gaussian profile of a laser beam
3 with the quadcell, the laser beam being emitted by the
4 scanning head.

1 75. The method of claim 67, wherein tracking the
2 angular movement of the scanning head across the
3 photostimulable medium, comprises:
4 tracking the position of an encoder attached to
5 the center of the body of the scanner.

1 76. The method of claim 75, wherein the encoder
2 comprises:
3 a plurality of marks disposed at an equal spacing
4 to one another extending partially around the circumference
5 of the encoder.

1 77. The method of claim 76, wherein tracking the
2 position of an encoder is performed by a plurality of
3 sensors disposed at equal radial distances around the



3 sensors disposed at equal radial distances around the
4 circumference of the encoder tracking the position of a
5 gradient strip wrapping partially around the encoder, the
6 gradient strip having a length equal to the distance between
7 two adjacent sensors.

1 78. The method of claim 67, wherein adjusting a
2 pixel sampling rate as the scanning head moves across a
3 photostimulable medium, comprises:

4 increasing the pixel sampling rate as the scanning
5 head moves across the center of the photostimulable medium;
6 and

7 decreasing the pixel sampling rate as the scanning
8 head moves across the edges of the photostimulable medium.

