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**FOCUS ERROR DETECTION USING PRISM-ENHANCED SPOT SIZE MONITORING**
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- (56) Prior Art Documents  
**US 4716283**
- (57) Claim

1. An apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

a light source for providing a primary light beam to said medium;

a prism positioned in an optical path of a return light beam reflected from said medium for reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor of M in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor of  $M^2$ ;

a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at said first and third areas with the amount of light at the second area and generating a focus error signal responsive thereto.

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COMPLETE SPECIFICATION

(ORIGINAL)

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Related Art:

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Complete Specification for the invention entitled:

Focus Error Detection Using Prism-Enhanced Spot Size  
Monitoring

The following statement is a full description of this invention, including the best method of performing it known to me/us

Abstract of the Disclosure

An apparatus and method is described for detecting focus errors in an optical head by positioning a prism in the optical path of a return light beam reflected from an optical recording medium. The prism reduces the beam in one dimension by a factor of M and concurrently increases the divergence/convergence angle associated with a focus-error of the beam by a factor of M in said dimension, thereby desirably enhancing the focus error signal by a factor of  $M^2$ . A focus error is detected by a segmented photodetector having inner and outer photosensitive regions. The photodetector generates an electrical signal indicative of the focus error from the difference in light intensities at the inner and outer regions. The photodetector preferably is segmented in such manner as to also provide a track error signal.



FOCUS-ERROR DETECTION USING PRISM-ENHANCED  
SPOT SIZE MONITORING

Technical Field

5 This invention relates to methods and means for  
detecting focus errors in optical heads adapted to read and  
write data on optical recording media, and more particularly  
relates to improved means for generating a focus error  
signal for use as input to a servo system operative to keep  
an optical beam in focus on a surface.

10 Background of the Invention

Focus-error detection methods heretofore used for  
optical storage applications generally employ a knife edge,  
an astigmatic lens or a critical angle prism. These  
techniques require very critical alignment of these optical  
15 elements and of a split or segmented photodetector.

Published European patent application EP 0164687  
discloses a detection technique wherein a laser beam  
reflected from an optical disk is directed through an  
objective lens to a prism that reduces beam width in one  
20 dimension by a factor  $M$  and delivers an elliptical beam to a  
knife-edge-type focus error detection system. This  
application, following equation (25), claims to increase the  
focus error signal by a factor of  $M$ .

The Digest of the Topical Meeting on Optical Data  
25 Storage, October 15-17, 1985 at Washington, D.C., includes  
Paper THCC2-1 by Yamamoto et al. entitled "Design  
Considerations of Optical Pregroove Dimension". This paper  
shows a six-element photodetector to detect the far field  
spot size variations associated with a focus error.

There is a need for a very sensitive focus error detection technique that will provide, with relatively few components, a significant enhancement of the focus error signal and provide a large beam size that only requires an uncritical alignment of a segmented photodetector in one dimension.

Summary of the Invention

In accordance with one aspect of the present invention there is disclosed an apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

a light source for providing a primary light beam to said medium;  
a prism positioned in an optical path of a return light beam reflected from said medium for reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor of M in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor of  $M^2$ ;

a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at said first and third areas with the amount of light at the second area and generating a focus error signal responsive thereto.

Toward this end and according to the invention, an apparatus and method are provided for detecting focus errors in an optical head by positioning a prism in the optical path of a return light beam reflected from an optical recording medium. The prism reduces the beam in one dimension by a factor of M and concurrently increases the divergence/convergence angle associated with a focus error of the beam by a factor of M in said dimension, thereby desirably enhancing the focus error signal by a factor of  $M^2$ . A focus error is detected by a segmented photodetector having inner and outer photosensitive regions,





Fig. 3 illustrates an optical head according to one embodiment of the invention for use with read-only, write-once or phase-change optical disks;

Fig. 4 illustrates an embodiment for use with an optical disk drive employing a swing-arm actuator; and

Fig. 5 illustrates an embodiment for use with magneto-optic disks.

### Description of Preferred Embodiments

#### General

10 The principle of the invention is best illustrated in Fig. 1. The output of a diode laser 10 is passed through a circularizer/collimator system 11 to provide a collimated beam 12. On reflection from a beam splitter 13, beam 12 becomes beam 14. Beam 14 is focused by a lens 15 onto surface 16 of an optical recording medium. When surface 16 is at the focus of lens 15, the collimated beam 14 from beam splitter 13 to lens 15 is retroreflected on itself and, as return beam 14, is transmitted by beam splitter 13 to a prism 17. Prism 17 refracts beam 14 as beam 18, which is directed to a photodetector 19. Beam 18 has an intensity pattern of elliptical configuration, with a major axis equal to D and a minor axis A. Prism 17 reduces the width of beam 14 by a factor of M (which is defined as D/A) to that of the refracted beam 18.

25 Assume now that the data on surface 16 is out of focus by an amount  $\delta z$ . Under this assumed condition, the beam 14' reflected from surface 16 will, after passing through lens 15, diverge with an angle  $\delta\theta$ , in which

$$\delta\theta = D\delta z/f^2 \quad (1)$$

30 where f is the focal length of lens 15.

If  $\delta z$  is negative, then  $\delta\theta$  will be negative and the beam 14' will converge. The following analysis considers the case of  $\delta z$  being positive, but when  $\delta z$  is small, the same analysis is valid for a diverging or converging beam 14'.

The refracted beam 18' emerging from prism 17 has a divergence angle of  $M\delta\theta$ ; and the width  $A'$  of said beam on detector 19 is now given by

$$A' = A + 2lM\delta\theta \quad (2)$$

where  $l$  is the distance from prism 17 to photodetector 19.

Using equation (1), one obtains

$$\begin{aligned} A' &= A + 2lMD\delta z/f^2 \\ &= A + 2lM^2A\delta z/f^2 \end{aligned}$$

or,

$$A'/A = 1 + 2lM^2\delta z/f^2 \quad (3)$$

It will thus be seen that, by inserting prism 17 in the path of the return beam 14' from surface 16, the change in beam width  $A$  indicative of a focus error  $\delta z$  is enhanced by a factor  $M^2$ .  $M$  is determined by the apex angle of prism 17, and by the refractive index of the material from which it is made.  $M$  may be made arbitrarily large; however, the tolerance on alignment of the system becomes increasingly tight as  $M$  increases. A practical maximum value for a single prism 17 is approximately  $M=5$ ; however, several prisms may be used in series and the resultant factor  $M$  would then be the product of the values of  $M$  for each prism.

As illustrated in Fig. 2A, photodetector 24 comprises three photosensitive striped areas 1,2,3. Let  $I_1, I_2, I_3$  be the electrical signals generated by the light incident on these photosensitive areas 1,2,3, respectively. For the configuration shown in Fig. 2A, let  $S_1 = I_1 + I_3$  and  $S_2 = I_2$ . Let  $kA$  be the width of central photosensitive area 2 where

$k(=0.25)$  is chosen such that  $S_1=S_2$  when beam 14 is in focus. If  $S_1'$  and  $S_2'$  are the signals corresponding to a focus error  $\delta z$ , it can be shown that

$$\frac{S_1'}{S_1} = \frac{2(A'-kA)}{A'+A-2kA}$$

$$\frac{S_2'}{S_2} = \frac{2(1-k)A}{A'+A-2kA}, \text{ and}$$

$$FES = \frac{S_1' - S_2'}{S_1 + S_2} = \frac{A' - A}{A'+A-2kA}$$

When  $A'=A$  and  $k=0.25$ ,

$$FES \approx 0.67(A'/A-1) \approx 1.31M^2\delta z/f^2$$

Thus, by way of example, if  $M=5$ ,  $l=50$  mm and  $f=4$  mm, then a small focus error  $\delta z=0.5$   $\mu\text{m}$  gives a focus error signal  $FES=0.05$ . This large error signal will allow detection of very small focus errors with high signal-to-noise ratio.

Signals  $I_1$  and  $I_3$  are summed and amplified at 20 to provide output signal  $S_1$ , whereas signal  $I_2$  is amplified at 21 to provide output signal  $S_2$ . Signals  $S_1$  and  $S_2$  are supplied to a differential amplifier 22 and a summing amplifier 26 whose outputs are supplied to divider circuit 28. The output of the divider circuit 28 is the focus error signal, FES. The focus error signal is applied to a focus servo control system 23 (Fig. 1). As illustrated, system 23 comprises conventional means (not shown) for adjusting the current in a coil 24 for thereby adjusting the position of lens 15 relative to surface 16.

The preferred configuration of photodetector is shown in Fig. 2B. Photodetector 25 includes six photosensitive areas 1-6 for generating electrical signals  $I_1-I_6$ , respectively. The focus error signal is given by

$$FES = \frac{S_1' - S_2'}{S_1 + S_2}$$

and the track error signal by

$$TES = \frac{S_3 - S_4}{S_3 + S_4}$$

where

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$$S_1 = I_1 + I_3 + I_4 + I_6$$
$$S_2 = I_2 + I_5$$
$$S_3 = I_1 + I_2 + I_3$$
$$S_4 = I_4 + I_5 + I_6$$

10 The manner in which the track error signal is used to adjust track error is conventional and forms no part of the present invention. Fig. 2B is included merely to show that applicants' method and means for detecting and correcting focus errors is compatible with and desirably used in conjunction with a photodetector like 25 that generates both focus error and track error signals.

15 Fig. 3

As illustrated in Fig. 3, the invention according to this embodiment comprises an optical head especially suitable for use with read-only, write-once or phase-change optical disks. A laser 30 emits a beam that is collimated by a lens 32 and circularized by refraction at surface 34 of a prism 46. Surface 34 has a polarizing beam splitter (PBS) coating. The beam 35 is directed through a quarter-wave plate 36 to a beam bender 38 and a lens 40 that focuses said beam onto a selectable track on an optical disk 42. The beam 35' reflected from disk 42 returns through the wave plate 36 and is reflected as beam 37 from surface 34 toward surface 44 of prism 46. Refraction of beam 37 at surface 44 reduces the width of said beam by a factor of M from D to A and directs this elliptical beam 47 to a photodetector 48

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30 that preferably is segmented as shown in Fig. 2A or 2B.

If, as illustrated in Fig. 3, the data on the track of disk 42 is in focus, then the return beam 35' will coincide with the beam 35, and the beam width at the photodetector 48 will be equal to A. If, however, the data on disk 42 is out of focus, then the return beam 35' will diverge from 35, and as illustrated in Fig. 1, cause the width of the beam to the photodetector 48 to be greater than A. As described in connection with Fig. 2, photodetector 48 will generate a FES; and the position of lens 40 relative to the tracks on the disk 42 will be adjusted in response to this FES by suitable servo means (not shown) as necessary to put the data in focus.

This embodiment requires a desirably low number of components.

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Fig. 4

Figs. 4A and 4B illustrate another embodiment of an optical head for use with read-only, write-once or phase-change disks. According to this embodiment, the general orientation of the head is parallel to the tracks on a disk 50. This head is therefore most easily adapted to a disk drive that employs a swing-arm actuator. A laser 52 (Fig. 4A) emits a beam that is collimated by a lens 54 and directed to and through a PBS 56 without deflection or reflection. Beam 58 from PBS 56 is elliptical in cross section, with a width D in one dimension and a width A in a direction orthogonal thereto. This beam 58 passes through a quarter-wave plate 60 and is directed to a prism assembly 62. At a first surface 64 of prism assembly 62, beam 58 is circularized, then reflected by total internal reflectance (TIR) from another surface 66 to and off a reflective surface 68 to an objective lens 70 that focuses the

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resultant beam 72 onto the disk 50. Beam 72 is reflected from a disk track as reflected beam 58'. Beam 58', which again is elliptical in cross section, is reflected by a surface 74 of the PBS 56 and directed to a photodetector 76 that preferably is segmented as shown in Fig. 2A or 2B.

If, as illustrated in Fig. 4, the data on the track of disk 50 is in focus, then the return beam 58' will coincide with the beam 58, and the beam width at the photodetector 76 will be equal to A. If, however, the data on disk 50 is out of focus, then the return beam 58' will diverge from 58, and as illustrated in Fig. 1, cause the width of the beam to the photodetector 76 to be greater than A. As described in connection with Fig. 2, photodetector 48 will generate a FES; and the position of lens 70 relative to the tracks on the disk 50 will be adjusted in response to this FES by suitable servo means (not shown) as necessary to put the data in focus.

This embodiment requires that the expansion/compression ratio M of prism 66 must be matched to the emission pattern of laser 52.

Fig 5

Fig. 5 illustrates still another embodiment of an optical head for use with magneto-optic disks. A laser 80 emits a beam that is collimated by a lens 82, circularized by refraction at surface 84 of a prism 86 and directed towards a beam bender 88 and an objective lens 90. Surface 84 is a partially polarizing beam splitter surface that directs a fraction of the p-polarized component of beam 92' as reflected from a selected track on disk 94, and substantially all of the s-polarized component of said beam to surface 98 of a prism 96 as a beam 100. Surface 98 is

also a partially-polarizing beam splitter surface. Surface 98 refracts a fraction of the p-polarized component of beam 100 as a beam 101 to a servo photodetector 102 preferably segmented as shown in Fig. 2A or 2B. This refraction causes a reduction in one dimension of beam 100 by a factor of M from D to A. Surface 98 also directs a fraction of the p-polarized component of beam 100 as well as substantially all of the s-polarized component of beam 100 as a beam 103 to a Wollaston prism 104, converging lens 106 and data detector 108. The function of the Wollaston prism in detecting the data on a magneto-optic disk is well known in the art and does not form part of the present invention.

If, as illustrated in Fig. 5, the data on the track of disk 94 is in focus, then the return beam 92' will coincide with the primary beam 92, and the beam width at the photodetector 102 will be equal to A. If, however, the data on disk 94 is out of focus, then the return beam 92' will diverge from 92, and as illustrated in Fig. 1, cause the width of the beam to the photodetector 102 to be greater than A. As described in connection with Fig. 2, photodetector 48 will generate a FES; and the position of lens 90 relative to the tracks on the disk 94 will be adjusted in response to this FES by suitable servo means (not shown) as necessary to put the data in focus.

It will now be seen that, in each of the configurations shown in Figs. 3-5, unlike those taught by the prior art, the focus error signal is desirably enhanced by a factor of  $M^2$ .

While the invention has been shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the

spirit and scope of the invention, and the invention is therefore not to be limited except as defined in the claims.

What is claimed is:

1. A method of determining the spirit and scope of an invention, comprising the steps of: (a) identifying the invention; (b) identifying the claims; (c) identifying the prior art; (d) comparing the invention with the prior art; (e) determining the spirit and scope of the invention; and (f) determining the claims.

2. A method of determining the spirit and scope of an invention, comprising the steps of: (a) identifying the invention; (b) identifying the claims; (c) identifying the prior art; (d) comparing the invention with the prior art; (e) determining the spirit and scope of the invention; and (f) determining the claims.

3. A method of determining the spirit and scope of an invention, comprising the steps of: (a) identifying the invention; (b) identifying the claims; (c) identifying the prior art; (d) comparing the invention with the prior art; (e) determining the spirit and scope of the invention; and (f) determining the claims.

4. A method of determining the spirit and scope of an invention, comprising the steps of: (a) identifying the invention; (b) identifying the claims; (c) identifying the prior art; (d) comparing the invention with the prior art; (e) determining the spirit and scope of the invention; and (f) determining the claims.

The claims defining the invention are as follows:

1. An apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

a light source for providing a primary light beam to said medium;

a prism positioned in an optical path of a return light beam reflected from said medium for reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor of M in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor of  $M^2$ ;

a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at said first and third areas with the amount of light at the second area and generating a focus error signal responsive thereto.

2. The apparatus of claim 1, wherein said second photosensitive area is centered between the first and third photosensitive areas such that the focus error signal generated is zero when the sum of the amount of light at the first and third photosensitive areas equals the amount of light at the second photosensitive area.

3. The apparatus of claim 2, wherein said second photosensitive area is in the form of a stripe between said first and third photosensitive areas and said first, second and third areas are further divided in a direction perpendicular to the stripe to create three upper and three lower photosensitive areas.

4. The apparatus of claim 1, 2 or 3, further including:

a focus lens located in the optical path of said primary beam for directing said primary beam onto said medium; and



servo means connected to the photodetector and the focus lens for adjusting the focus lens relative to the medium responsive to said focus error signal.

5. An apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

a light generation means for providing a primary beam of collimated light;  
a prism having one surface for circularizing said primary beam;  
a quarter-wave plate for receiving said primary beam from said prism;

a lens for focusing said primary beam from the quarter-wave plate onto said medium;

said prism being positioned in the optical path of a return light beam reflected from the medium for reducing said return light beam in one dimension by a factor  $M$  and concurrently increasing the divergence/convergence angle of said return light beam by a factor of  $M$  in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor  $M^2$ ;

a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at the first and third areas with the amount of light at the second area and generating a focus error signal responsive thereto.

6. An apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

a light generation means for providing a primary beam of collimated light;

a quarter-wave plate for receiving said primary beam;



a prism having one surface for circularizing the primary beam from the quarter-wave plate, a second surface from which the circularized light is reflected by total internal reflection, and a third surface which is reflective;

a lens for focussing the beam reflected from said third surface onto the medium;

said prism being positioned in the optical path of a return light beam reflected from the medium for reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor of M in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor of  $M^2$ ;

a polarizing beamsplitter for receiving said return light beam from said prism;

a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at the first and third areas with the amount of light at the second area and generating a focus error signal responsive thereto.

7. A method for detecting a focus error in an optical head to which a light beam is directed for reading and/or writing data on an optical recording medium, the steps comprising:

positioning a prism in an optical path of a return light beam reflected from said medium for reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor of M in said dimension, whereby a change in said dimension of said return light beam indicative of said focus error of said head is enhanced by a factor  $M^2$ ;

providing a photodetector located in said optical path for receiving an unobstructed return light beam from the prism, the



photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return light beam; and

comparing the sum of the amount of light at the first and third photosensitive areas with the amount of light at the second photosensitive area and generating a focus error signal responsive thereto.

8. The method of claim 7, wherein said second photosensitive area is centered between the first and third photosensitive areas such that the focus error signal generated is zero when the sum of the amount of light at the first and third photosensitive areas equals the amount of light at the second photosensitive area.

9. The method of claim 8, wherein said second photosensitive area is in the form of a stripe between said first and third photosensitive areas and said first, second and third areas are further divided in a direction perpendicular to the stripe to create three upper and three lower photosensitive areas.

10. The method of claim 7, 8 or 9, further including the step of adjusting the position of a focussing lens within the optical path in response to said focus error signal as necessary to cause the sum of the amount of light at the first and third photosensitive areas to equal the amount of light at the second photosensitive area.

11. An apparatus for detecting a focus error in an optical head adapted to read and/or write data on an optical recording medium, comprising:

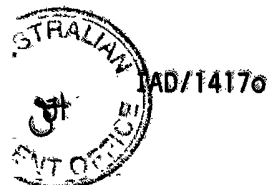
a light generation means for providing a primary beam of collimated light;

a first prism for circularizing said primary beam by refraction;

a lens for focussing said primary beam from the first prism onto the medium;

a second prism;

said first prism being positioned in the optical path of a return light beam reflected from the medium, the first prism having a partially polarizing beamsplitter surface for directing a fraction of a



p-polarized component of said return beam and substantially all of a s-polarized component of said return light beam to the second prism;

said second prism having a partially polarizing beamsplitter surface for refracting a fraction of the p-polarized component of said return light beam from the first prism, and said second prism reducing said return light beam in one dimension by a factor of M and concurrently increasing the divergence/convergence angle of said return light beam by a factor M in said dimensions, whereby a change in said dimensions of said return light beam indicative of said focus error of said head is enhanced by a factor of  $M^2$ ;

a photodetector located in said optical path for receiving an unobstructed return light beam from the second prism, the photodetector having a first, second and third photosensitive areas located proximate one another along said dimension of said return beam; and

a circuit connected to the photodetector for comparing the sum of the amount of light at the first and third photosensitive areas with the amount of light at the second photosensitive area and generating a focus error signal responsive thereto.

12. Apparatus for detecting a focus error in an optical head substantially as described herein with reference to any one of the drawings.

DATED this FOURTEENTH day of JANUARY 1992

International Business Machines Corporation

Patent Attorneys for the Applicant  
SPRUSON & FERGUSON



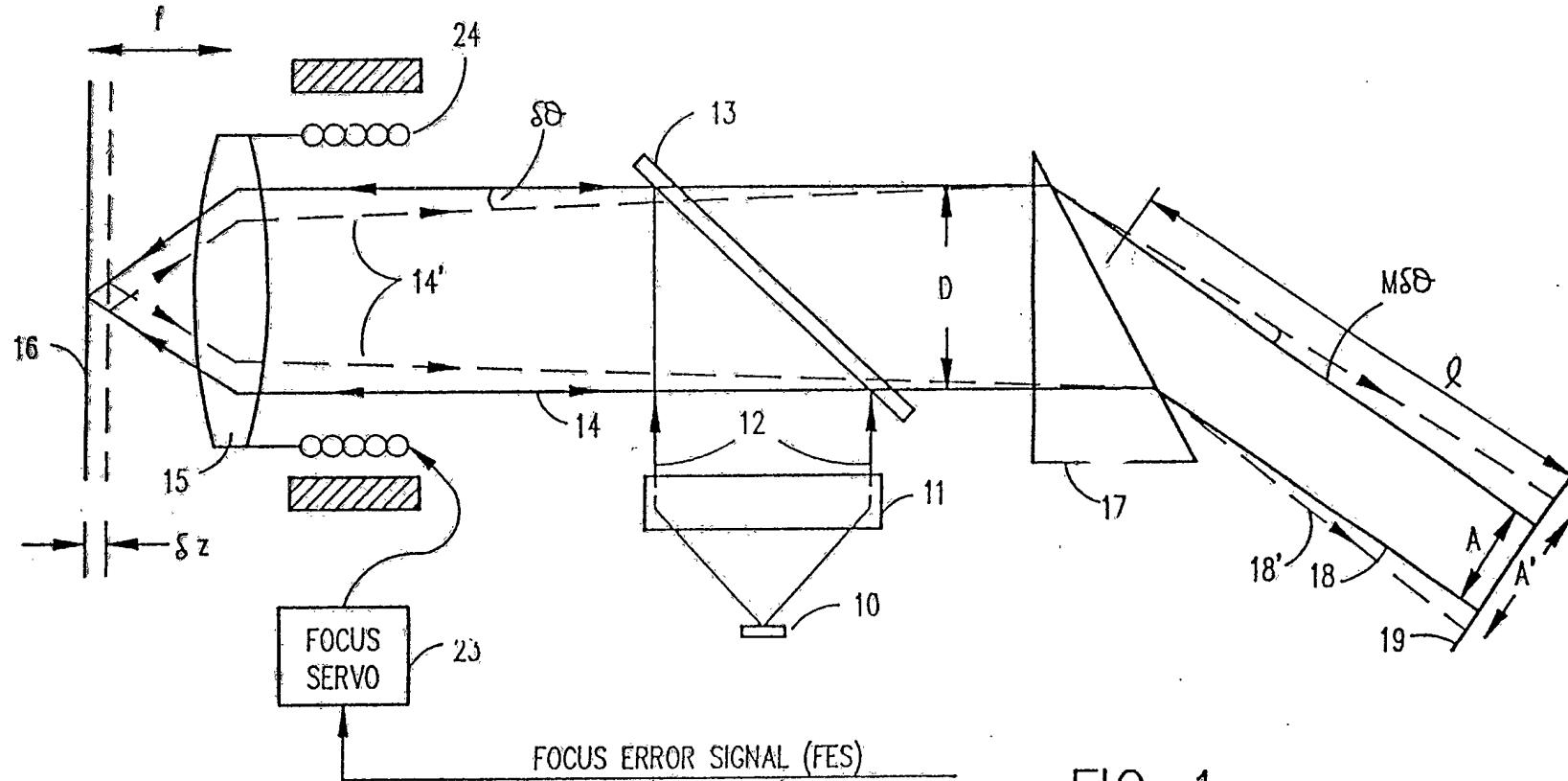
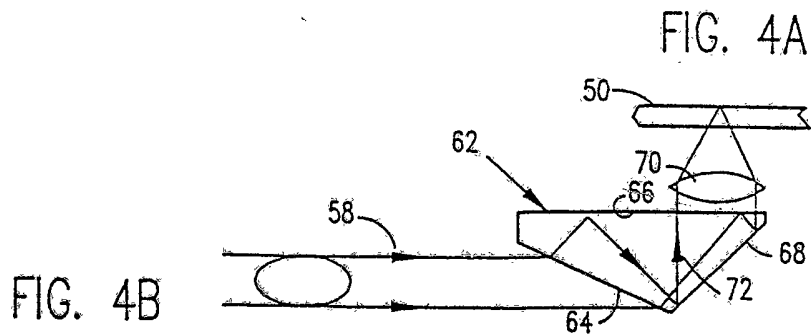
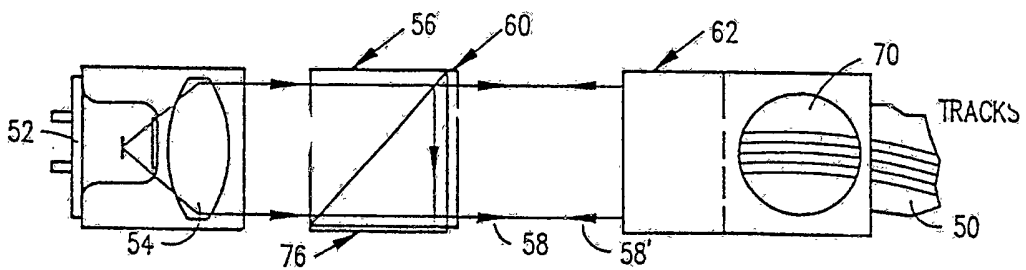
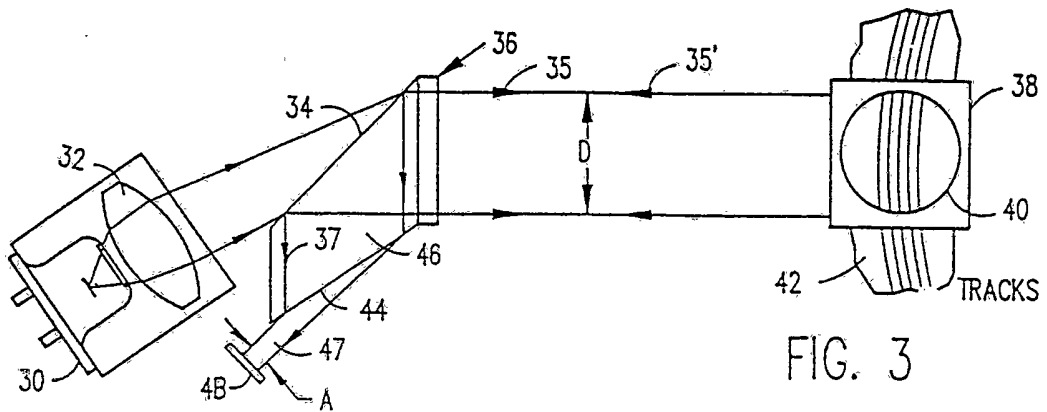
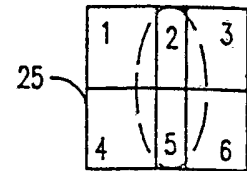
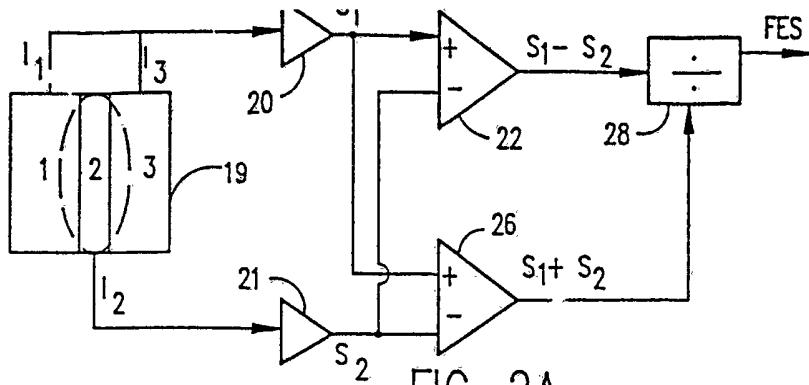


FIG. 1



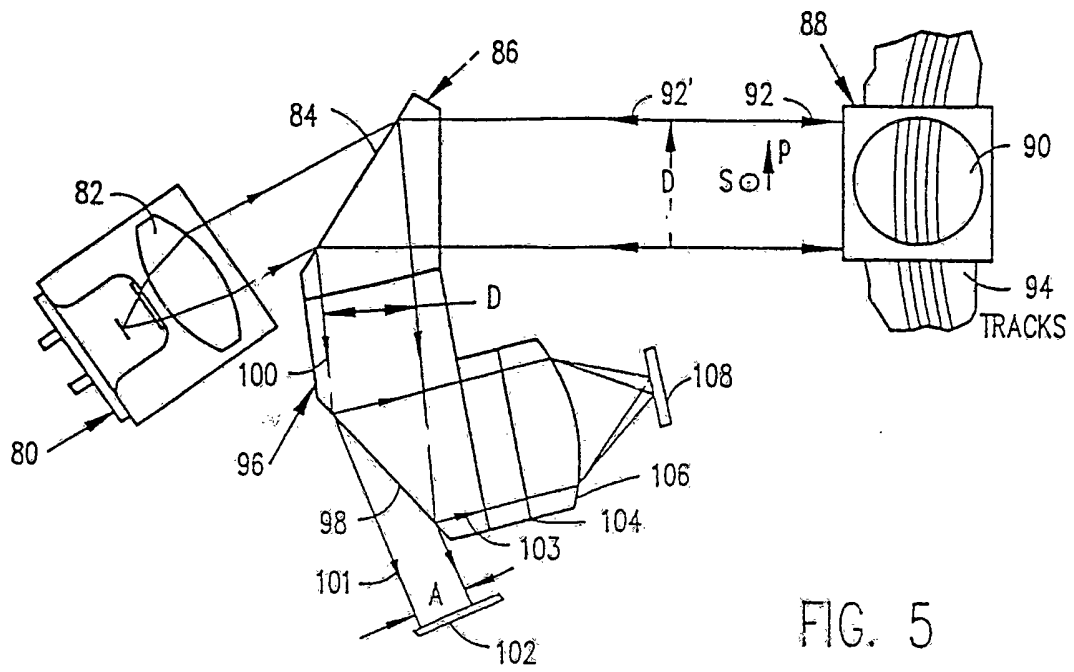


FIG. 5