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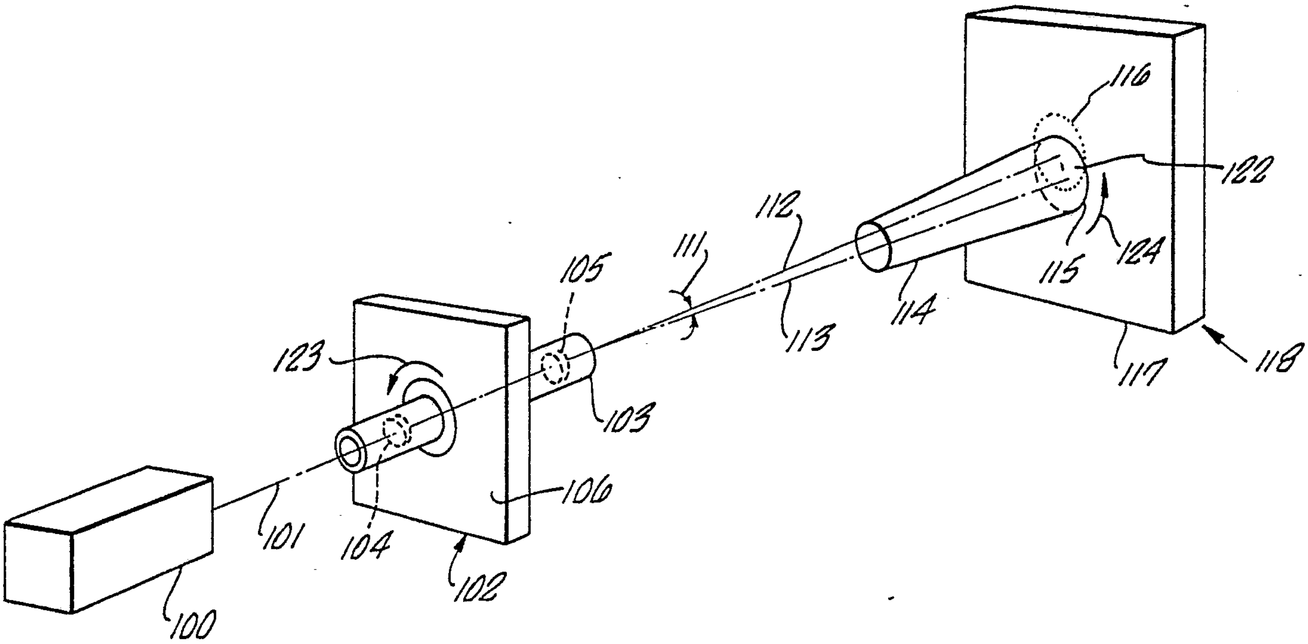
(54) Title: METHOD AND MEANS OF BEAM APODIZATION



(57) Abstract

An electromagnetic radiation beam (101) with Gaussian intensity profile is at least partly apodized by conically scanning the beam. The beam could alternatively have a non-Gaussian profile with a symmetry about its maximum and its point of inflection. Wedge prisms (104, 105) are rotated to effect deflection of a laser beam so that an apodized time-averaged uniform distribution (121) is obtained in the far field. Over-apodization produces an intensity profile (131) which provides a highly sensitive means for detecting relative motion, such as optical tracking.

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DESCRIPTION

METHOD AND MEANS OF BEAM APODIZATION

Background of the Invention

This invention relates to scanning beams which have a symmetry about their maximum intensity point, such as a Gaussian beam, or a beam having a peak with a maximum intensity having additionally symmetries about their points of inflection. In particular the invention is directed to apodizing laser beams whereby the time-averaged intensity profile of such a beam is flattened so as to be of substantially uniform intensity.

A laser beam typically has a Gaussian distribution as its intensity profile. That is, if the intensity, I, were plotted against the distance from the center of the beam, y, that function takes the form of the expression $I=I_oe^{-by2}$ where the constant Io defines the intensity on the beam axis, and the constant, b, defines the beam width. The expression is exact both close to the laser which in the art is termed "the near field" and far away from the laser which in the art is termed "the far field." In the near field, the constant, b, is a linear measure usually given in millimeters. In the far field, the constant, b, is an angular measure normally given in milliradians.

When such a beam is apodized, deliberate steps are taken to flatten this Gaussian intensity profile distribution, namely, to make the intensity, I, a constant independent of position in the beam, y. The constant intensity distribution should prevail for some useful distance away from the beam axis.

In the prior art, apodization is most often done in the near field by placing a graded radially symmetrical filter in the beam. The filter is appropriately designed to absorb more strongly at the center than at the edges.

The beam immediately beyond the filter then has the desired flat intensity profile, but undesirably it is much weaker than before. The filter is usually also expensive and difficult to make to the required absorption and optical wave-front tolerances, and it can also be deteriorated by the laser beam intensity. Finally, diffraction effects at the beam edges will cause the intensity in the far field much beyond the filter to revert again to a non-flat distribution.

Such absorption apodization also wastes the light energy and deteriorates the laser light intensity.

Scanning a beam with a Gaussian profile is the rotation of the beam about an axis, and symmetrical scanning about the central beam axis produces no change in the intensity profile anywhere along the beam. In fields dealing with beams of electromagnetic radiation, namely the radar,infrared and laser field, scanning of the beams has been effected to create different objectives all totally unrelated to apodization.

In U.S. Patent 3,226,721 (Gould) there is disclosed a plurality of optical scanning devices that utilize a rotating tube which have various internal optical elements such as lenses and prisms to effect a raster scan or a conical scan. Thereby Gould, which is like an antenna, is able to locate a target or object within a desired field of view. Gould provides a radar pointing effect, which causes a sharp angle of intersection between rotating lobes of the radar beam, which is usually non-Gaussian.

In U.S. Patent 2,975,668 (Eckel) there is disclosed a scanning device with a rotating tube which effectively is no more than a periscope to change the field of view.

U.S. Patent 4,034,949 (Hoesterey) discloses an optical tracking system where the lens defines an optical axis for use with infra red telescopes for sensing the flight path of a rocket or missile by tracking heat-radiating portions of a missile. The optical-mechanical means provides a nutation of received radiation energy so as to trace a circular image upon a detected array about the optical axis. Once again this does not relate to apodizing a Gaussian beam, but rather targeting or pointing.

Thus in the prior art there does not exist the method or means for scanning a Gaussian beam of electromagnetic radiation to effect at least substantial apodization. Where such scanning is effected in a transmitter of such radiation, it can enhance the radiation beam pointing.

Summary of the Invention

There is provided a method and means for at least partially apodizing a beam of electromagnetic radiation having a substantially Gaussian intensity cross-sectional profile or a symmetry about their points of inflection by scanning the beam about an axis which is not the central beam axis.

The point of inflection in a curve profile is that point at which the curvature changes from concave upwards to concave downwards or vice versa.

With a laser beam at least substantially apodized it is possible to obtain a beam having a uniform time-averaged intensity where the intensity profile is flattened thereby to provide a laser beam with at least a uniform time-averaged intensity distribution.

An over-apodized laser beam provides a profile along the beam central axis that is reduced to a trough so that a low point is reached where sensitivity to variation of the intensity is maximized.

Apodization in the far field is effected by conically scanning the beam about an axis inclined to the central beam axis so that the peak intensity at the center of the originating laser beam traces out a cone in space. Except for the direction along the axis of conical rotation, a point at any other direction illuminated by scanning the beam shows a periodic fluctuation intensity. The intensity is a maximum when the laser points closest to such point and a minimum when the laser points farthest away from such point.

By scanning the beam about an axis parallel to its central axis, but removed from the central axis, a cylindrical scan provides near field apodization.

The time-averaged intensity of the beam is obtained by averaging the intensity over at least one scan.

Brief Description of the Drawings

Figure 1 is a diagramatic view illustrating a conical scan of a laser beam of Gaussian profile.

Figure 2 is a detailed diagramatic view of a conical scan mechanism to effect scanning of the beam.

Figure 3 shows representative contours indicating the normalized intensity for a laser beam of Gaussian shape representative of a cross-section through a typical laser beam in the far field.

Figure 4 is an apodized beam profile in the far field of a laser beam plotted with a normalized time averaged intensity as a function of distance measured perpendicularly to the conical scan axis.

Detailed Description

Apparatus for scanning a Gaussian electromagnetic beam of electromagnetic radiation includes a laser source 100 to project a laser beam 101 through a conical scan mechanism 102. The mechanism includes a rotating housing 103 which has a pair of wedge prisms 104 and 105 mounted in the housing axially spaced apart from each other on the longitudinal axis of the housing 103.

The detailed diagramatic view of the housing 103 shows a support 106 having bearing means 107 so that the housing 103 can rotate therein. The rotating housing 103 is driven by motorized means which has a gear system 108 connected to the output shaft 109 of a motor 110.

The prisms 104 and 105 are relatively rotatable to each other in the housing and, after this is effected as desired locking screws set the prisms 104 and 105 in a position at a selected radial angle relative to each other. With the prisms 104 and 105 so locked there is requisite deflection of the laser beam 101 as indicated by the angle 111 between the non-deflected central axis 112 of the laser beam 101 and the central axis 113 of the deflected laser beam.

Such deflected laser beam would transcribe a conical shape as illustrated by the diverging cone 114 which over a scan cycle transcribes a circle 115.

The peak of the apodized Gaussian beam in its conical scan about the laser non-deflected axis 112 traces a circle depicted by dotted lines 116.

The two circles 115 and 116 are illustrated in the far field as being on the plane 117 of a retroreflector 118.

As reflected from the retroreflector 118 the center line of the laser retroreflector axis 112 when the conical scanning mechanism 102 correctly aligns the transmission of the laser beam along axis 112.

In Figure 3 there is described in the far field at approximately 1.5 kilometers from the laser source 100 the contours of normalized intensity (I/Io) for the laser beam 101 of Gaussian shape. The contour interval equal 0.1 units and the beam axis which would be of the non-deflected laser beam is directed through the intersection of the x and y axes at the origin. This point would be equivalent to the central axis 119 point of intersection on the retroreflector 118. The x and y axes represent distances measured in meters perpendicular to the beam axis 112. The concentration of the contour lines between the normalized values of 0.4 and 0.7 are representative of the Gaussian distribution as depicted by the formula e^{-by^2}.

Comparatively in Figure 4 the apodized beam profile at the retroreflector 118 positioned at a far field distance of approximately 1.5 kilometers from the laser source 100 is shown. The normalized time averaged intensity is plotted as a function of distance perpendicular to the conical scan axis which would be equivalent to the central axis 113 shown in Figure 1. The preferred averaging time is greater than 10 scan cycles, and for comparison purposes a normalized Gausian distribution curve is shown as dashed curve 120. The apodized curve is depicted as curve 121. The effective operative width of the curve is illustrated between points 125 and 126. The beam so apodized shows substantially only low loss of intensity substantially adjacent the central beam axis 113.

By the conical scan of the laser beam 101 the time-averaged value of the periodically varying illumination off the scanned axis 113 has been found to be remarkably near equal to the constant illumination on the scan axis 113 at the far field where the long path length is between about 1.5 to 2 kilometers.

The conical scan mechanism 102 is shown as a mechanical device, with a pair of wedge prisms 104 and 105. To increase the speed of conical scanning it is possible to scan the beam electronically without using moving parts. Alternatively where time is not essential moving mirrors could form the equivalent function of the rotating wedge prisms 104 and 105.

The reference point 122 on the retroreflector 118 is randomly selected to illustrate the invention, and at that point 122 the intensity will fluctuate periodically. It will be maximum when the laser beam as illustrated by cone 114 points closest to 112 and minimum when the laser beam 114 points farthest away from 112. The time-average value of the periodically varying intensity off the scan axis at 122 can be made nearly equal to the intensity sensed on the axis by properly selecting the scanning angle 111. In other words, the time-average beam profile can be shaped to be remarkably flat in the vicinity of the distant retro-reflector 118.

The direction of scan as effected by the conical scan mechanism 102 is indicated by arrows 123 on the diagramatic conical scan mechanism 102 and also by the arrow 124 on the retroreflector 118.

The laser beam 101 can also be scanned to provide near field apodization. This is effected by cylindrically scanning the laser beam 101 about an axis parallel to axis 112, but which axis is not the central axis 112. One exemplary application such an apodized laser beam 101 in the near field is to enhance its properties for investigative effects in high density materials in water or the like.

In some cases a combination of both near field and far field apodization to greater or lesser degrees of apodization can be effected thereby to obtain the requisite intensity profile of the Gaussian beam 101. The effects of near field and far field apodizing are, in this sense, additive.

When using the apodized laser beam 101 in the far field, a transmissometer application can be obtained with the apodized beam. This transmissometer application is more fully described in my co-pending application Serial No. (attorney's docket 160/30) in which I am a co-inventor, and which is being filed simultaneously with the present application. Contents of that application are incorporated by reference herein.

Another application of the apodized beam exists where the beam is over-apodized as in curve 131 so as to provide a low intensity trough 127 between two peaks 128 and 129 which are shown in the dotted profile in Figure 4. At the low intensity trough point 127 there will a maximized sensitivity to the position of the apodized laser beam. This application of the apodized beam is effective to enhance the measurement of beam pointing or relative position movement change between a selected generating point associated with the laser source 100 and a selected beam receiving point associated with a reflector 118. Further details of this application are disclosed in the co-pending application aforementioned, which includes sensitive detection of earth movement.

In cases where it is necessary for the information contained within the laser beam to be transmitted rapidly the mechanical conical scan monitoring system 102 may be replaced by electronic scanning which effects scanning rapidly without the use of moving parts.

The apodized beam according to the invention has substantial improvements over apodizing methods and means for apodized beams which are currently known and as such provides a highly effective apodized beam with low loss of intensity for useful applications, some of which have been mentioned.

In other embodiments of the invention the beam 101 may be some other form of light which may or may not be monochromatic. The beam should have a symmetry either about its maximum intensity point 130, in the Gaussian profile described. Alternatively there should be a symmetry about the points of inflection and the maximum intensity in a non-Gaussian beam. In an example of Gaussian curve 120 the points 132 and 133 are the points of inflection, namely where the curvature of the profile changes from concave upwards to concave downwards.

Many changes and variations may be made in the method and construction providing widely different embodiments and applications for this invention without departing from the scope thereof. All matter contained in the above description as shown in the accompanying drawings shall be interpreted as illustrative and not limiting, the invention being interpreted solely by the scope of the appended claims.

Claims:

1. A method of scanning a beam of electromagnetic radiation, said beam having an intensity cross sectional profile and being substantially symmetrical about the maximum intensity point and points of inflection of said profile and having a central beam axis thereby to at least partially apodize the beam comprising directing the beam into scanning means, scanning the beam about an axis which is not the central beam axis, and outputting the scanned beam from the scanning means, the outputted scanned beam having an at least partially apodized time-averaged intensity profile at least at a predetermined point from the scanning means.

2. The method as claimed in claim I wherein scanning is effected about an axis which is non-parallel to the central beam axis.

3. The method as claimed in claim 1 wherein scanning is effected about an axis parallel to the central beam axis.

4. The method as claimed in claim 2 wherein scanning produces an effectively conical scan.

5. The method as claimed in claim 3 wherein scanning is additively effected conically about an axis which is non-parallel to the central beam axis.

6. The method as claimed in claim 4 wherein the beam enters the scanning means along a central axis of the scanning means and scanning effectively deflects the output beam from the central axis.

7. The method as claimed in any one of the above claims wherein the beam is substantially apodized and the beam is selected to be a laser beam.

8. The method as claimed in claim 7 wherein the beam is apodized to effect only substantially low loss of the beam intensity along and substantially adjacent the central beam axis.

9. The method as claimed in claim 7 wherein the beam is substantially fully apodized across its effective operating width.

10. The method as claimed in claim 7 wherein scanning effects near field apodizing.

11. The method as claimed in claim 7 wherein scanning effects far field apodizing.

12. The method as claimed in claim 7 wherein scanning effects near and far field apodizing.

13. The method as claimed in claim 7 wherein scanning is effected to over-apodize the beam thereby to produce a low intensity trough substantially about the central beam axis.

14. The method as claimed in claim 13 wherein over-apodization is effected in substantially the far field.

15. The method as claimed in claim 7 wherein scanning is effected over several scans to apodize substantially the time averaged intensity of the beam.

16. The method as claimed in claim 7 wherein scanning of the beam is effected thereby to enhance pointing of the beam.

17. The method as claimed in claim 7 wherein scanning of the beam is effected thereby to enhance measurement of the relative motion substantially between a selected generating point and a selected beam receiving point.

18. The method as claimed in any one of claims 1 to 6 wherein scanning is effected by passsing the beam through wedge prisms rotatable about an axis substantially coincidental with the central axis of the beam entering the scanning means.

19. The method as claimed in claim 18 wherein the beam is substantially apodized and the beam is selected as a laser beam.

20. The method as claimed in claim 7 wherein scanning is effected by reflecting the beam on relatively movable mirrors.

21. The method as claimed in claim 7 wherein scanning the beam is effected electronically.

22. Apparatus for scanning a beam of electromagnetic radiation, said beam having a intensity cross-sectional profile being substantially symmetrical about the maximum intensity point and points of inflection of said profile and having a central beam axis thereby to at least partially apodize said beam comprising a housing having a longitudinal axis, inlet means for the beam to enter through one end of the housing substantially along the longitudinal axis, outlet means for the beam to exit through an opposite longitudinal end of the housing, substantially wedge-like prisms means mounted within the

housing and being rotatable about the longitudinal axis to deflect the beam whereby on rotation of the prisms about the longitudinal axis the beam is scanned about a beam axis which is not the central beam axis, such that the output beam has at least a partly apodized time-averaged intensity profile at a predetermined point from the scanning means.

23. Apparatus as claimed in claim 22 wherein the wedge prisms means includes a pair of prisms, the members of the pair being spaced from each other longitudinally along the beam axis, and the amount of beam deflection being determined by the relative radial angle between the members of the wedge prisms.

24. Apparatus as claimed in claim 23 wherein the wedge prisms are adapted to effect a conical scan of the beam.

25. Apparatus as claimed in any one of claims 22 to 24 including motorized means for effecting rotation of the housing and thereby the wedge prisms about the longitudinal axis, gear means interconnecting a drive shaft from a motor with the housing, and the housing being mounted on bearing means thereby to facilitate rotation.

26. A method of scanning a laser beam said beam having a substantially Gaussian intensity cross sectional profile and having a central beam axis thereby to at least substantially apodize the beam comprising directing the beam into scanning means, scanning the beam about an axis which is not the central beam axis to produce a conical scan, and outputting the scanned beam from the scanning means, the scanned beam having an at least substantially apodized time-averaged intensity profile at a predetermined far field point from the scanning means.

27. The method as claimed in claim 26 wherein the beam is substantially fully apodized across its effective operating width at said predetermined point.

28. The method as claimed in claim 27 wherein scanning is effected over several scans to apodize substantially the time-averaged intensity of the beam.

29. The method as claimed in claim 28 wherein scanning is effected by passing the beam through wedge prism means rotatable about an axis substantially coincidental with the central axis of the beam entering the scanning means.

30. The method as claimed in claim 29 wherein the wedge prism means are relatively rotated about the axis of the beam until a selected relative radial angle between the prism means is obtained to provide the requisite degree of apodization to the beam, and the prism means is thereafter relatively fixed radially to each other during scanning.

31. The method as claimed in any one of claims 26 to 30 wherein the beam is apodized to effect only substantially low loss of the beam intensity along and substantially adjacent the central beam axis.

32. A method of scanning a laser beam said beam having a substantially Gaussian intensity cross sectional profile and having a central beam axis thereby to at least substantially over-apodize the beam comprising directing the beam into scanning means, scanning the beam about an axis which is not the central beam axis to produce a conical scan, and outputting the scanned beam from the scanning means, the scanned beam having an at least substantially apodized time-averaged intensity profile at a predetermined far field point from the scanning means, and a low intensity trough substantially about the central beam axis.

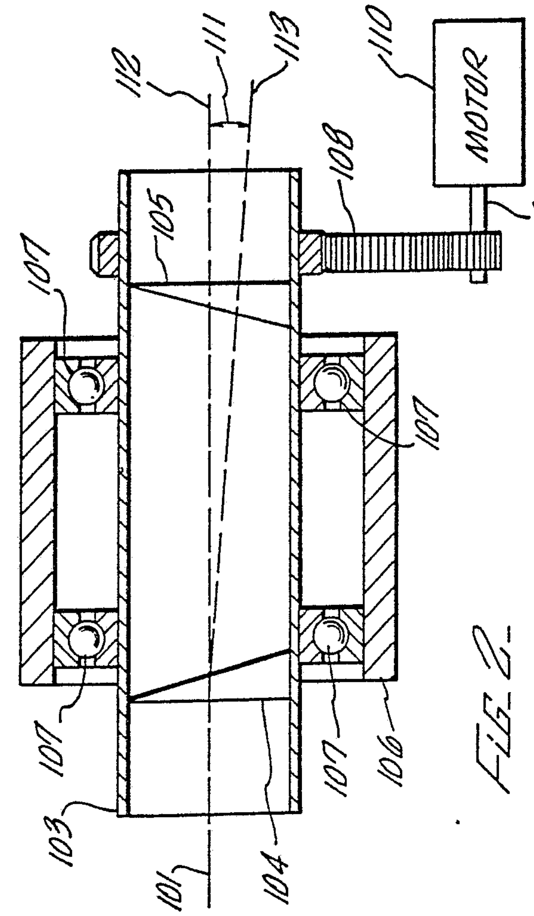
33. The method as claimed in claim 32 wherein scanning of the beam is effected thereby to enhance measurement of the relative motion substantially between a selected generating point and a selected beam receiving point.

34. The method as claimed in either of claims 32 or 33 wherein scanning is effected by passing the beam through wedge prisms rotatable about an axis substantially coincidental with the central axis of the beam entering the scanning means.

35. The method as claimed in claim 34 wherein the wedge prisms are rotated relative to each other about the axis of the beam until the selected radial angle between the prisms is obtained to provide the requisite degree of apodization to the beam, and the prisms are thereafter relatively fixed radially to each other during scanning.

36. Apparatus for conically scanning a laser beam said beam having a substantially Gaussian intensity cross sectional profile and having a central beam axis thereby to at least substantially apodize said beam comprising a housing having a longitudinal axis, inlet means for the beam to enter through one end of the housing substantially along the longitudinal axis, outlet means for the beam to exit through an opposite longitudinal end of the housing, substantially wedgelike prisms means mounted within the housing and being rotatable about the longitudinal axis to deflect the beam whereby on rotation of the prisms about the longitudinal axis the beam is conically scanned about a beam axis which is not the central beam axis, such that the output beam has substantially apodized time-averaged intensity profile at a predetermined point from the scanning means, the wedge prisms means including a pair of prisms, the members of the prism pair being spaced from each other longitudinally along the beam axis, and the

amount of beam deflection being determined by the relative radial angle between the members of the wedge prisms.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MOTOR
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105
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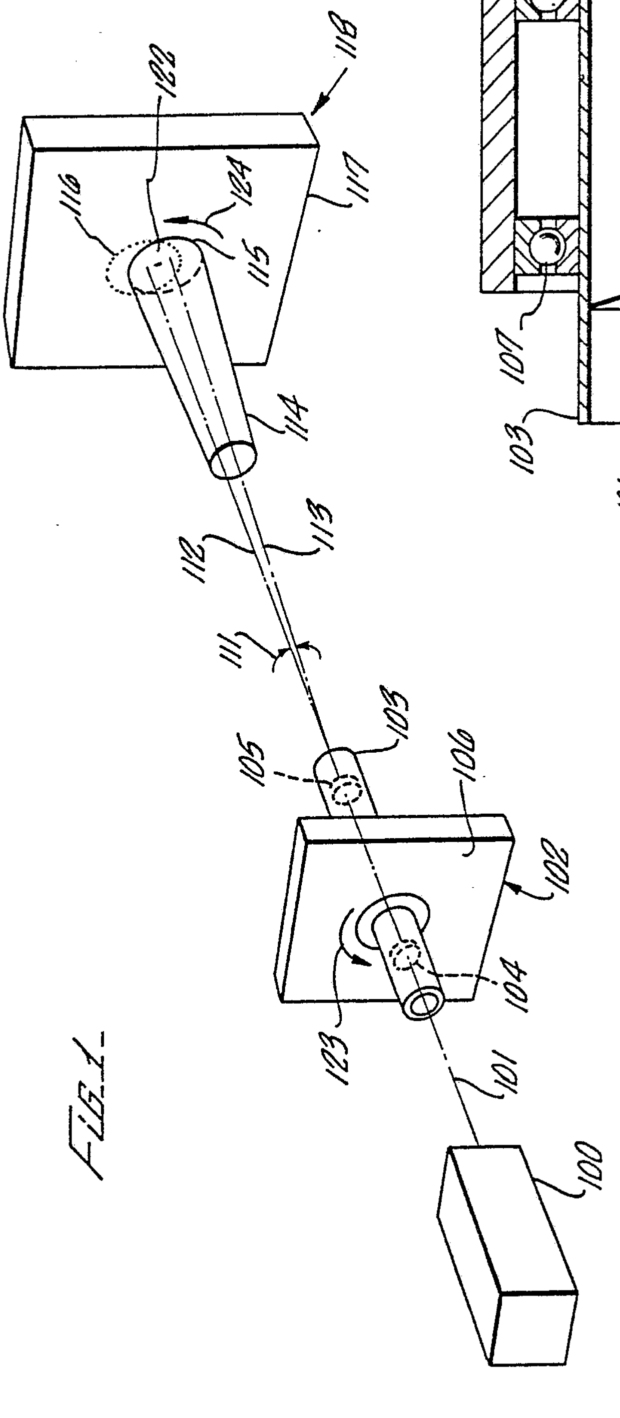
107
107
106
103
101
104

FIG. 2


118
122
116
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114
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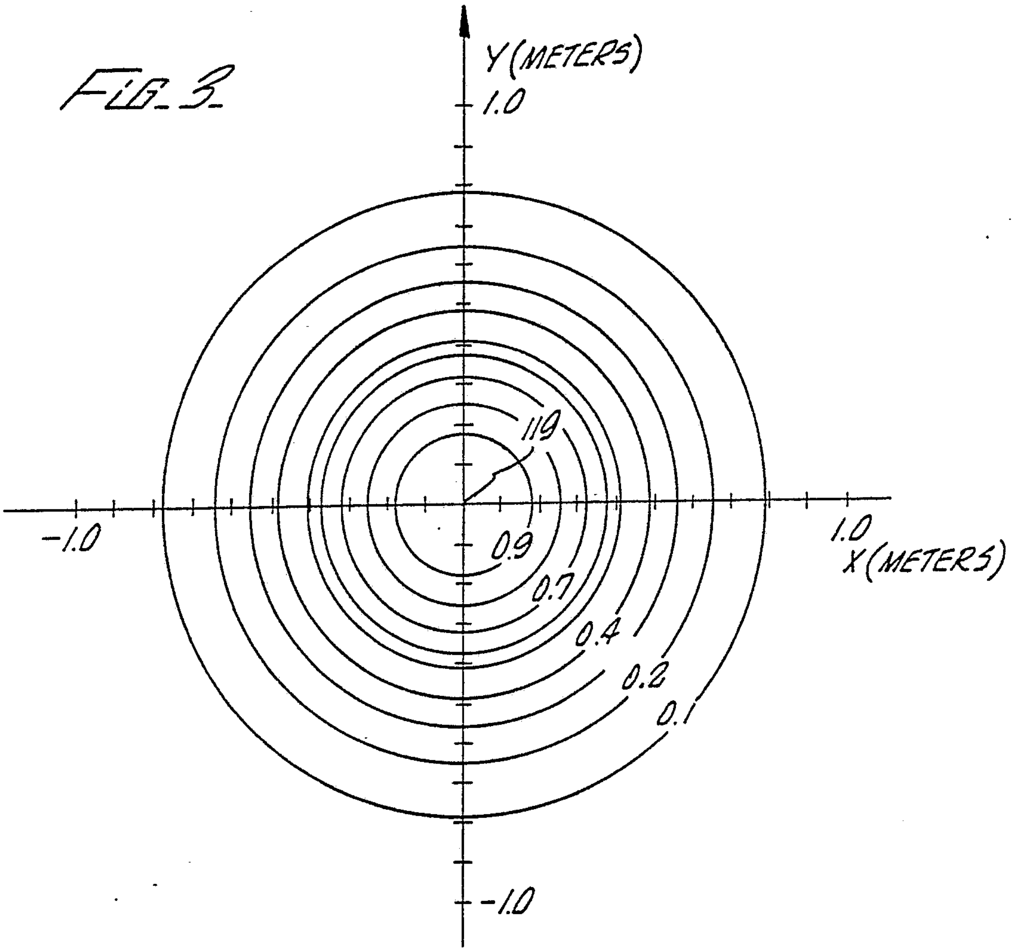
113
111
105
103
106
102
104
123
101
100

FIG. 1

FIG. 3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1.0
X (METERS)
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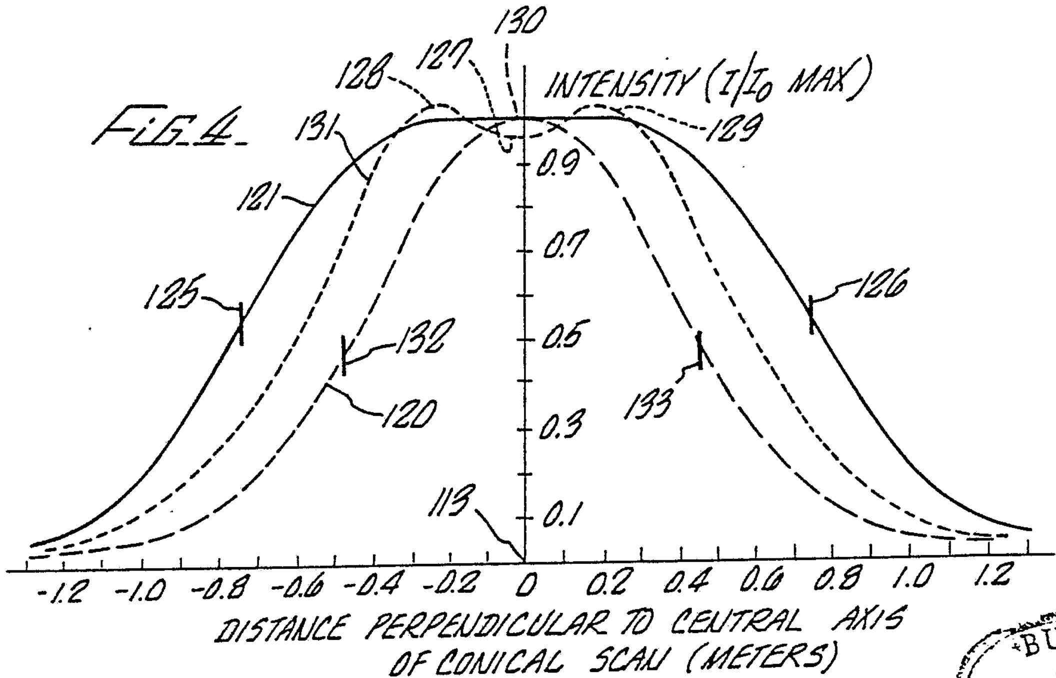
0.1
-1.0

FIG. 4


130
128
127
INTENSITY (I/I0 MAX)
129
131
121
0.9
0.7
125
126
132
0.5
120
133
0.3
113
0.1
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0 1.2
DISTANCE PERPENDICULAR TO CENTRAL AXIS
OF CONICAL SCAN (METERS)

INTERNATIONAL SEARCH REPORT

International Application No PCT/US83/00144

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[3] GO2B 27/17; GO2F 1/29
US. CL. 350/6.4, 6.9, 380

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	350/6.4, 6.9, 380

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 2,975,668, (ECKEL) 21 March 1961	1-9,22-36
Y	US, A, 3,226,721, (GOULD) 28 December 1965	1-19,22-36
Y	US, A, 3,378,687, (SCHEPLER) 16 April 1968	1-19,22-26
Y	US, A, 4,034,949, (HOESTEREY ET AL) 12 July 1977	1-19,22-26
A	US, A, 3,651,256, (SHERMAN ET AL) 21 March 1972	20
A	US, A, 4,128,297, (BOURNE) 5 DECEMBER 1978	20
A	US, A, 3,040,625, (ZITO) 26 June 1962	21
A	US, A, 3,499,701, (MACEK ET AL) 10 March 1970	21

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
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ISA/US	Rebecca D. Gass (signature) Rebecca D. Gass