United States Patent [19]

Sherman, Jr.

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[45] **July 1, 1975**

[54] **CATOPTRIC SYSTEM FOR SIMULTANEOUS CONCENTRATION OF LIGHT, LASER, AND OTHER TYPE PARAXIAL RAYS INTO BEAMS**

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[21] Appl. No.: **352,466**

[52] **U.S. Cl.** **350/294**; 350/293; 350/299

[51] **Int. Cl.** **G02d 5/10**

[58] **Field of Search** 350/288, 293, 294, 299, 350/199

[56] **References Cited**

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Primary Examiner—Alfred E. Smith
Assistant Examiner—Michael J. Tokar
Attorney, Agent, or Firm—Otto John Munz

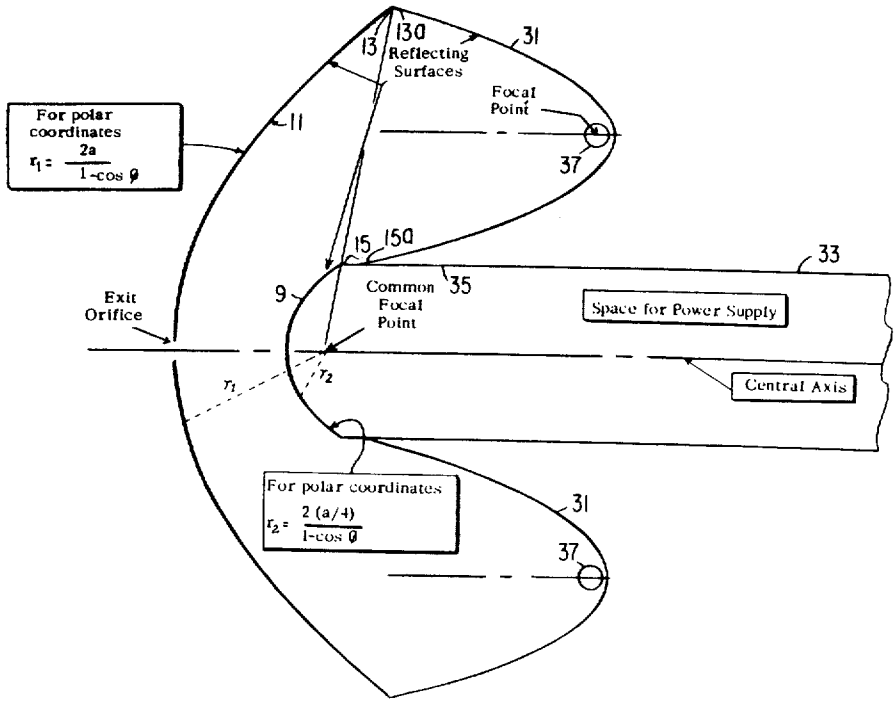
[57] **ABSTRACT**

A light concentrator of paraxial rays emanating from at least one point source and/or of multidirectionally dispersed rays, employing at least two confocal warped shells generated by the revolution of a conic section, has in a preferred embodiment two truncated confocal paraboloids, an outer of a larger dimension and an inner of a smaller dimension, mounted about a common axis with their vertices in line on one side of the common focal point of their surfaces. The inner face of the outer shell and the outer face of the inner shell are developed at least over selected portions thereof as reflectors. The vertex of the outer shell has an exit orifice for the passing of a concentrated beam therethrough, said beam originating in unconcentrated form from an area spaced opposite from the open ends of the paraboloids.

The direction of paraxial rays from the source, the arrangement of the confocal warped shells, and the angles of the reflectors are correlated into a multiple reflection system to produce the desired concentration and emission of a high-intensity beam through the vertex of the outer shell.

A paraxial ray reflected from the interior face of the outer paraboloid toward its focal point, impinges on the exterior face of the inner paraboloid, having the same focal point, and is reflected from there parallel to the direction of the original light ray and the common axis of the two paraboloids in continuous or stepwise successive reflections, whereby the light intensity of each ray contributes to the light intensity of the resultant common beam.

8 Claims, 26 Drawing Figures



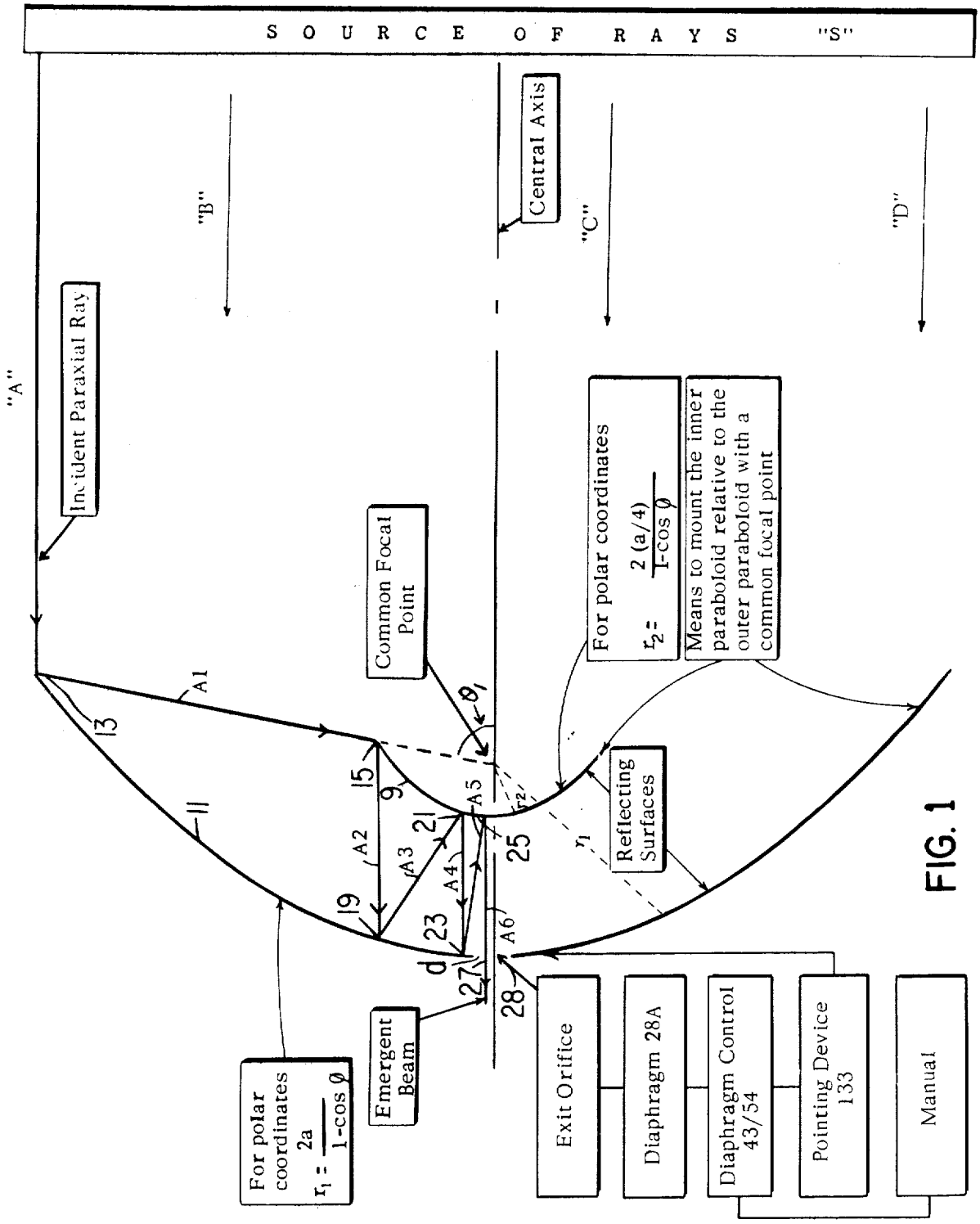

SOURCE OF RAYS "S"
"A"
"B"
"C"
"D"
Central Axis
Incident Paraxial Ray
Common Focal Point
For polar coordinates
$r_2 = \frac{2\,(a/4)}{1-\cos\phi}$
Means to mount the inner paraboloid relative to the outer paraboloid with a common focal point
Reflecting Surfaces
For polar coordinates
$r_1 = \frac{2a}{1-\cos\phi}$
Emergent Beam
Exit Orifice
Diaphragm 28A
Diaphragm Control 43/54
Pointing Device 133
Manual
A1
A2
A3
A4
A5
A6
11
13
15
19
21
23
25
27
28
9
d

FIG. 1

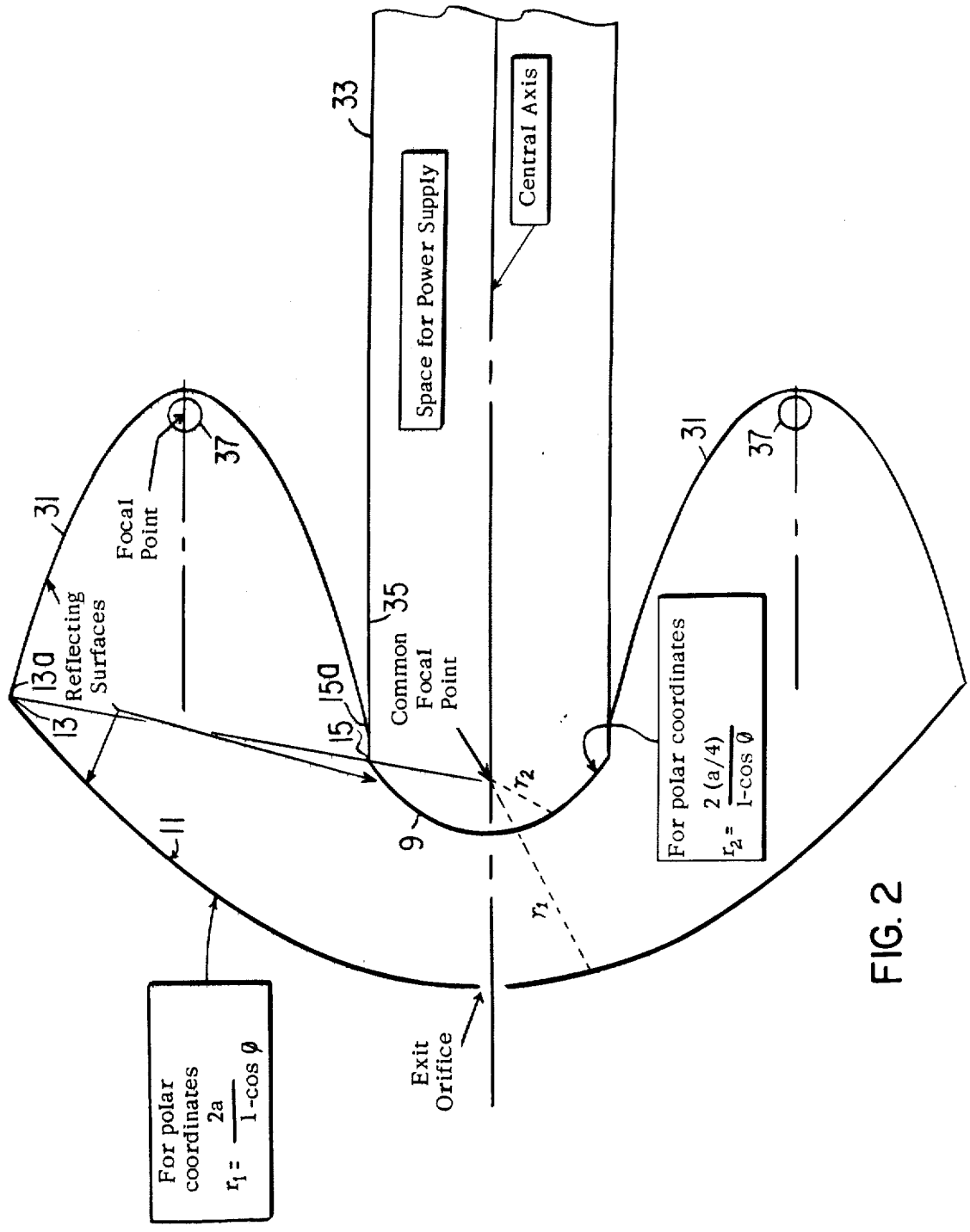

33
Central Axis
Space for Power Supply
31
37
Focal Point
130
Reflecting Surfaces
13
15
150
35
Common Focal Point
r_2
9
11
r_1
Exit Orifice
For polar coordinates
$r_1 = \frac{2a}{1-\cos\phi}$
For polar coordinates
$r_2 = \frac{2(a/4)}{1-\cos\phi}$

FIG. 2

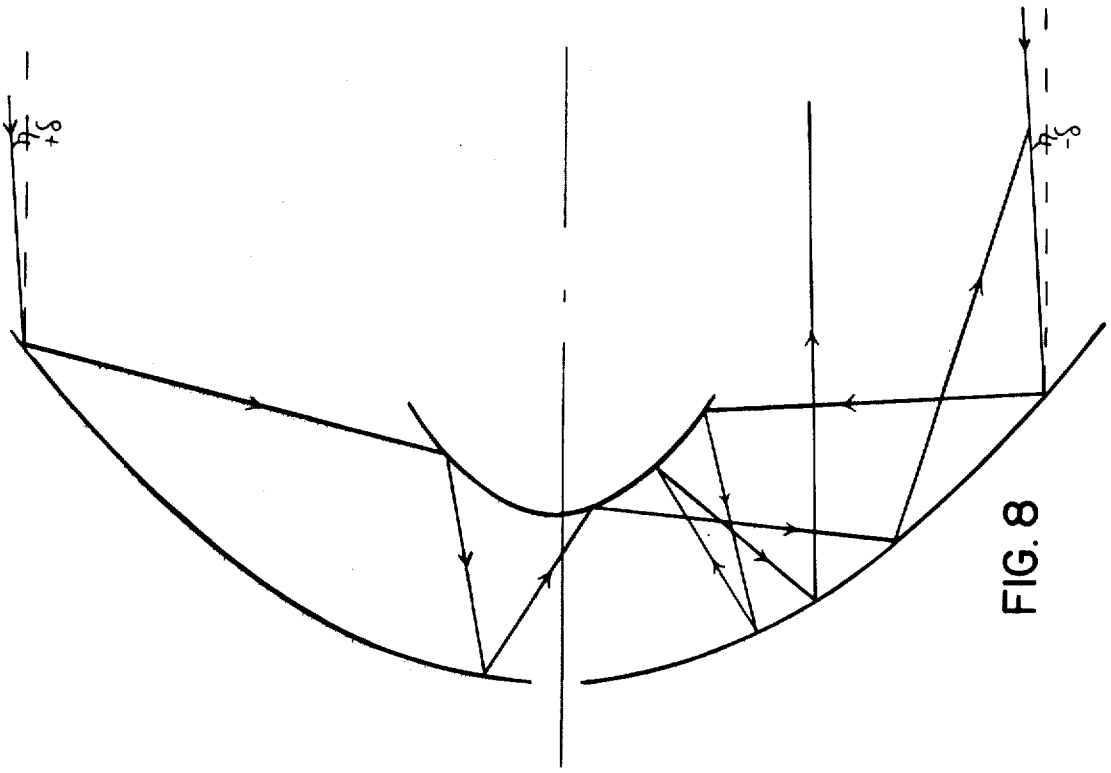


FIG. 8

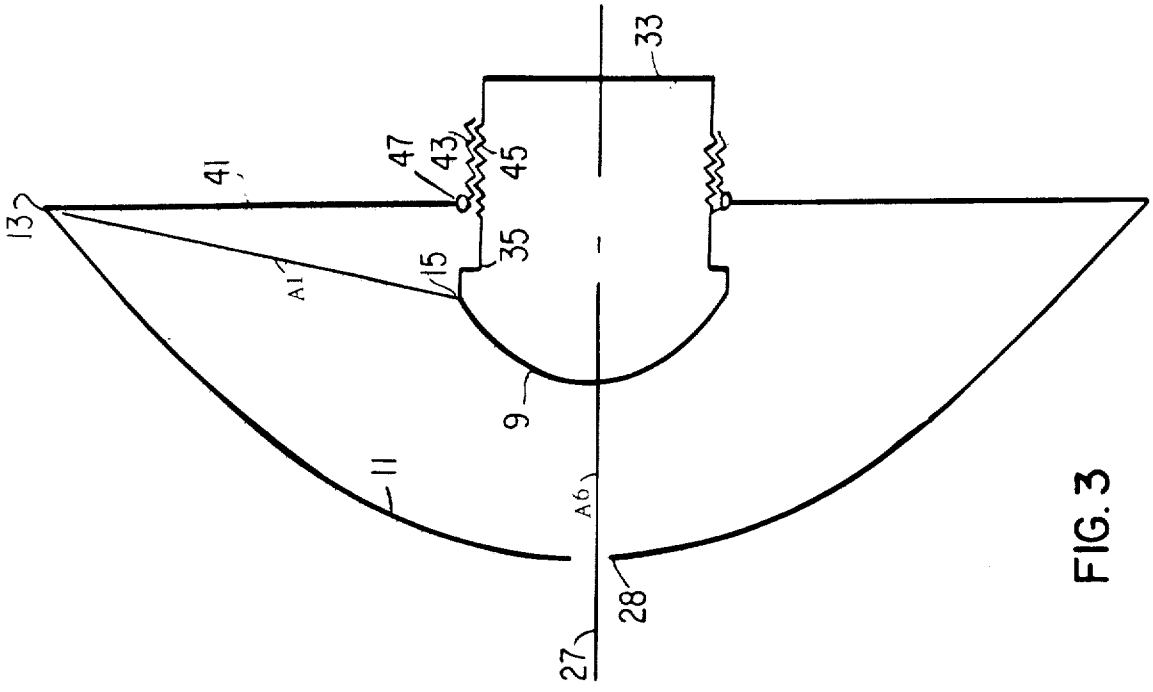


FIG. 3

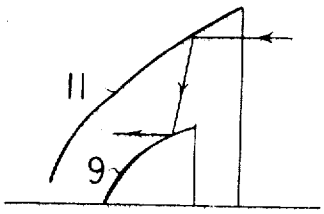


FIG. 4A

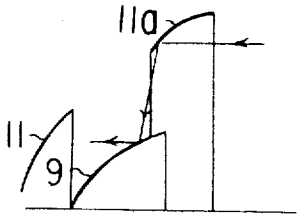


FIG. 4B

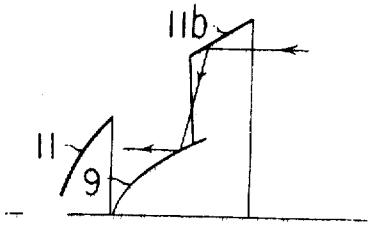


FIG. 4C

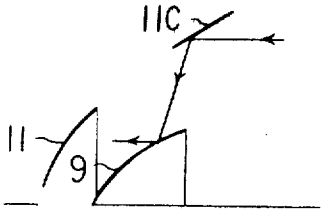


FIG. 4D

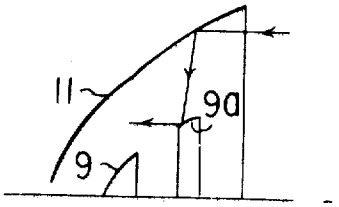


FIG. 4E

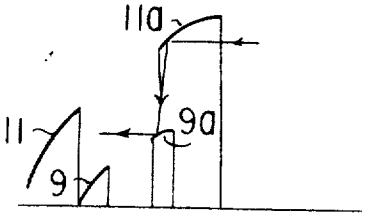


FIG. 4F

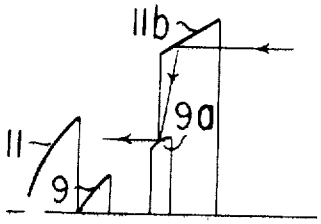


FIG. 4G

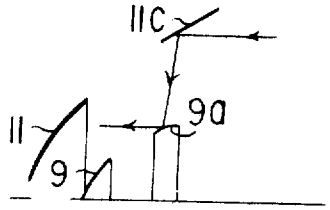


FIG. 4H

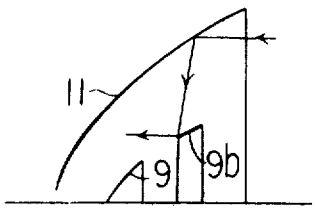


FIG. 4 I

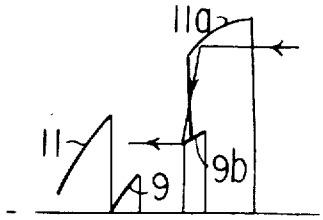


FIG. 4 J

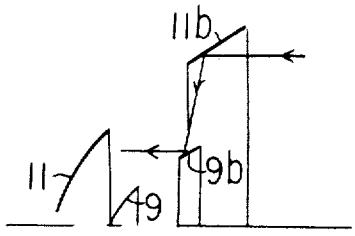


FIG. 4 K

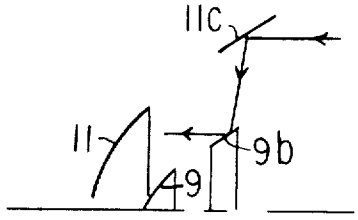


FIG. 4 L

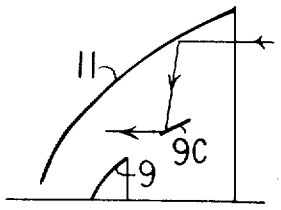


FIG. 4 M

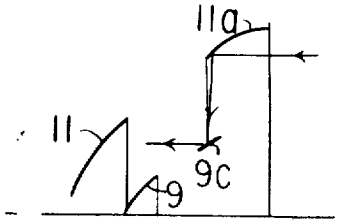


FIG. 4 N

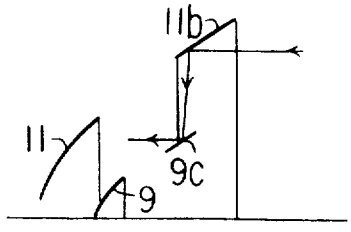


FIG. 4 O

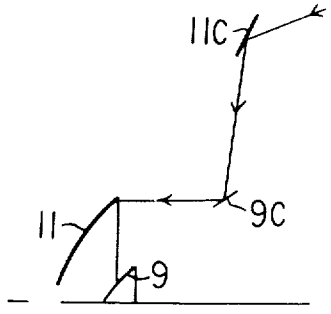


FIG. 4 P

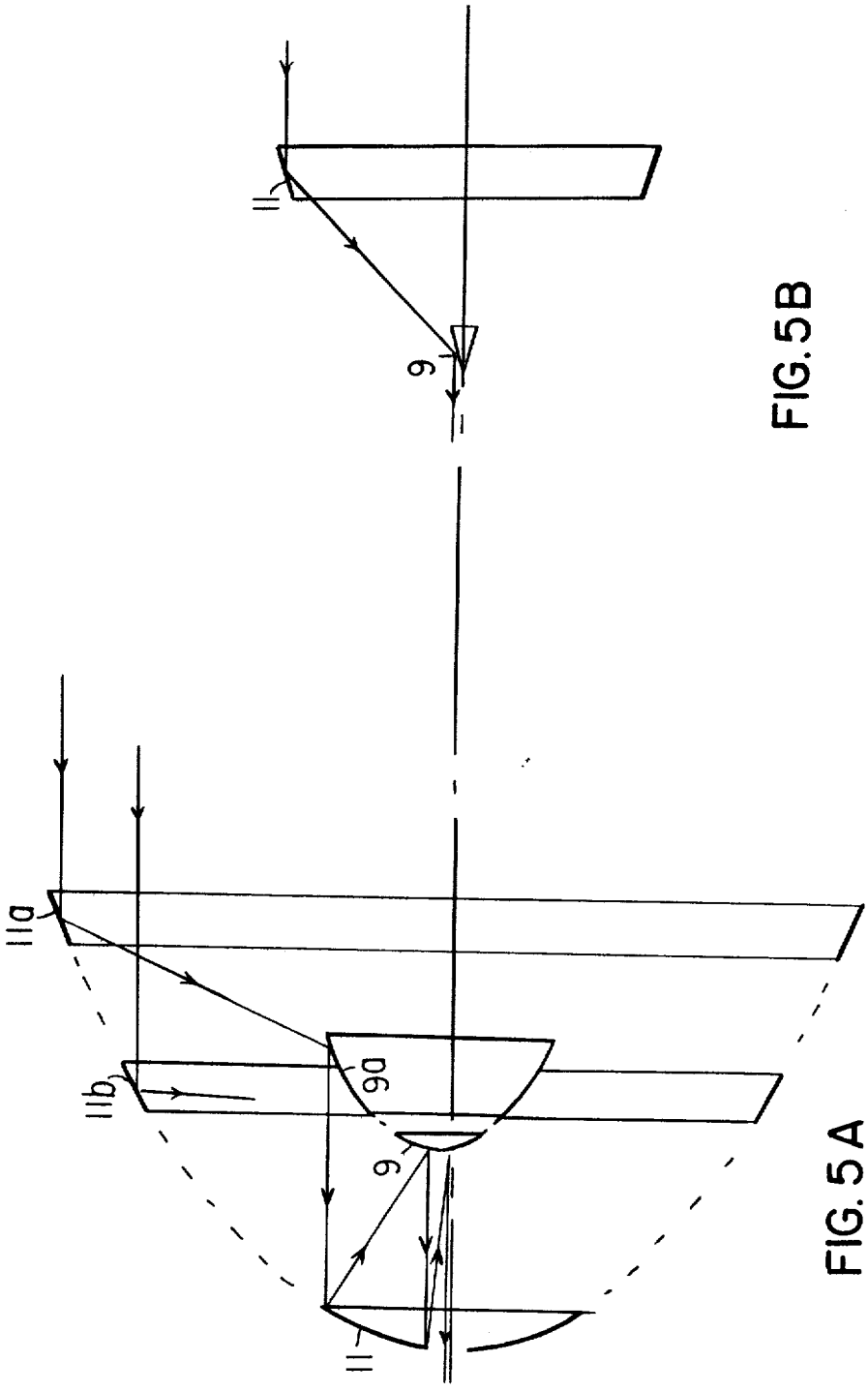


FIG. 5B

FIG. 5A

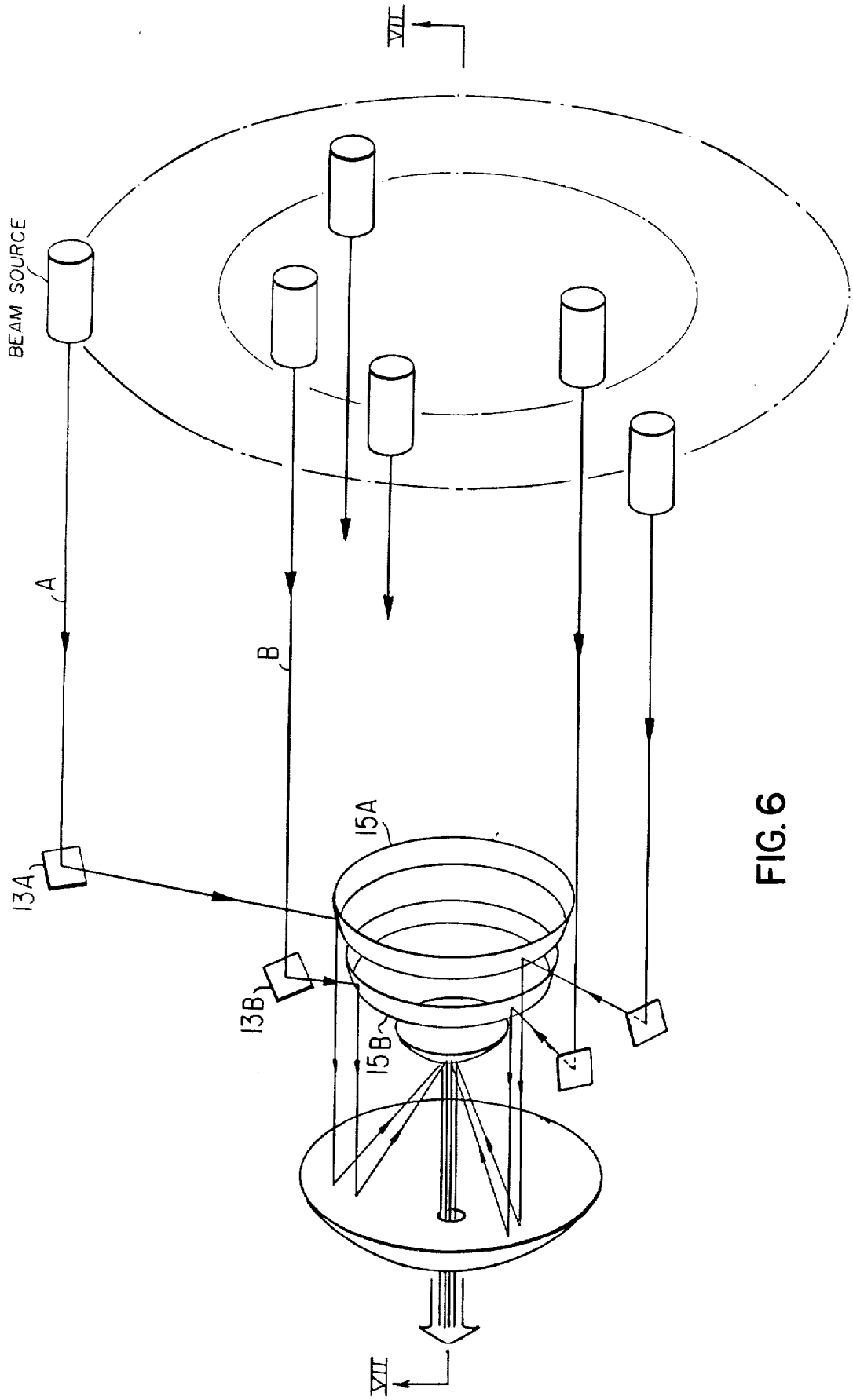


FIG. 6

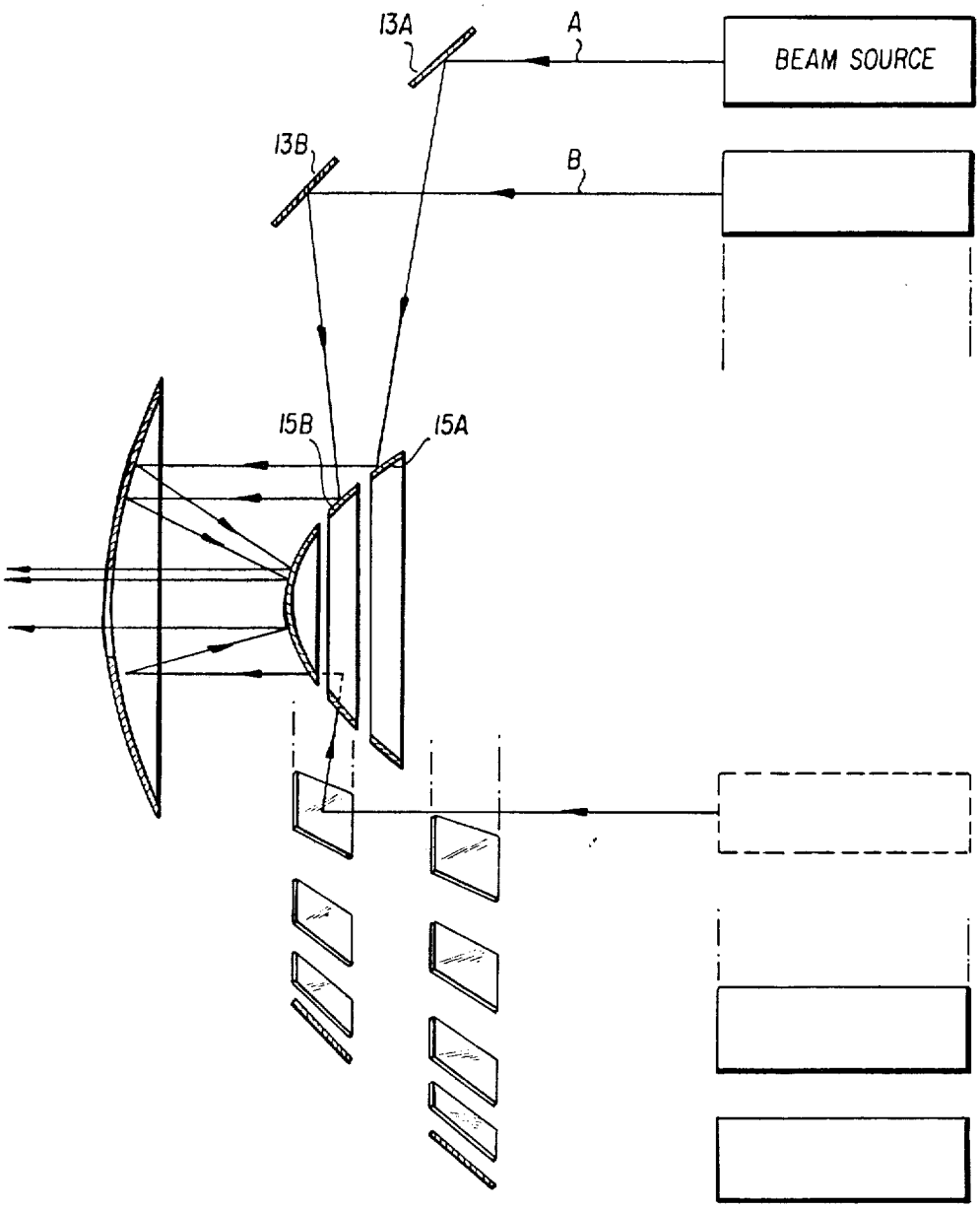


FIG. 7

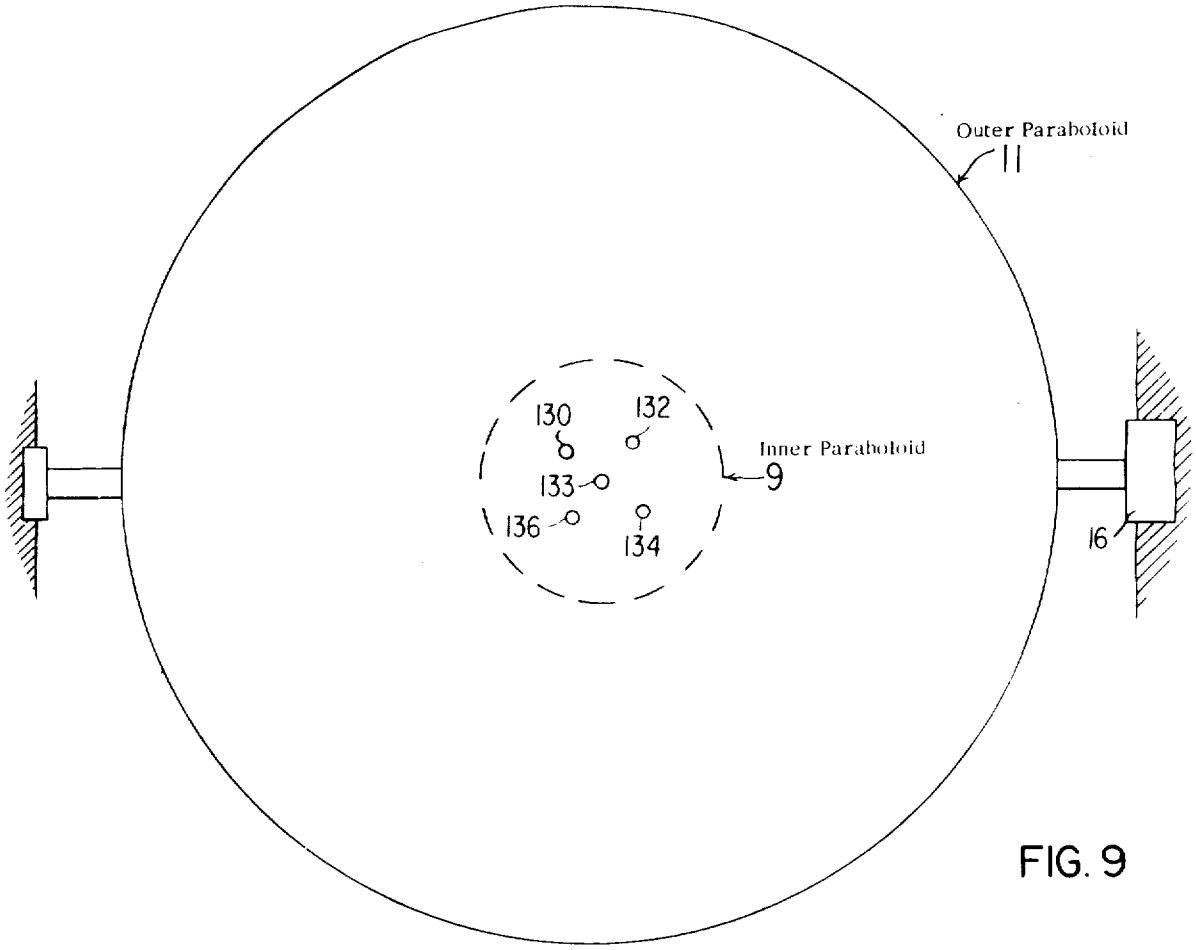

Outer Paraboloid
11
130
132
133
136
134
Inner Paraboloid
9
16

FIG. 9

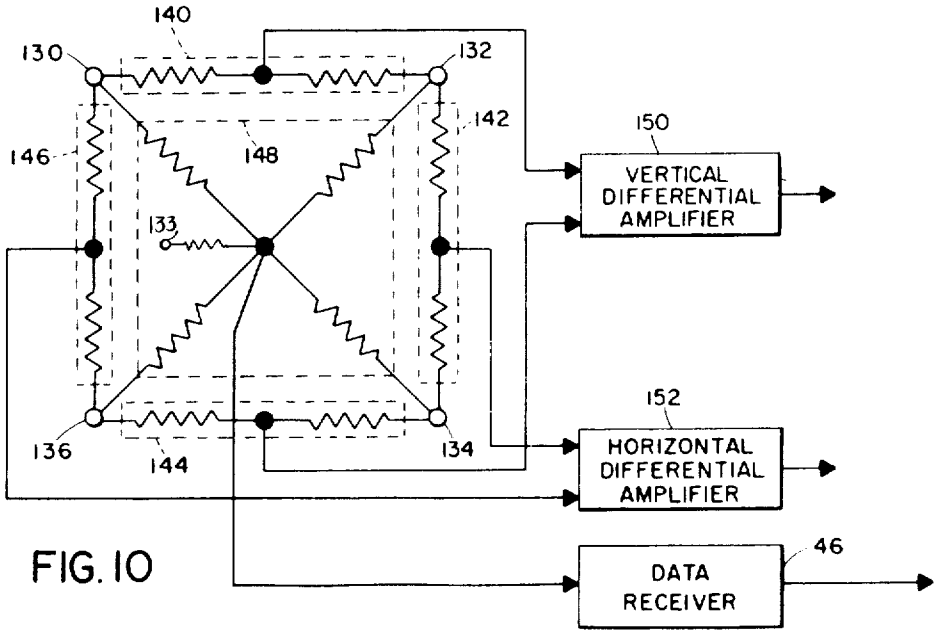

140
130
132
142
146
148
150
VERTICAL DIFFERENTIAL AMPLIFIER
133
152
HORIZONTAL DIFFERENTIAL AMPLIFIER
136
144
134
46
DATA RECEIVER

FIG. 10

CATOPTRIC SYSTEM FOR SIMULTANEOUS CONCENTRATION OF LIGHT, LASER, AND OTHER TYPE PARAXIAL RAYS INTO BEAMS

BACKGROUND OF THE INVENTION

1. Field of the Invention

A catoptric reflecting device employing confocal paraboloids for concentrating rays into a well defined beam of a reduced diameter. (Class 350, Subclass 294)

2. Description of the Prior Art

The prior art is represented by U.S. Pat. No. 2,457,253, issued Dec. 28, 1948 to C. Martin for a Reflecting Objective System; U.S. Pat. No. 2,534,543 issued Dec. 19, 1950 to J. T. Bullock for Light Concentrating Reflector Camera, and U.S. Pat. No. 3,407,122 issued Oct. 22, 1968 to B.W. Dickinson III for a Solar Still With a Casegranian Optical System. The systems of the prior art employ each a single reflection from each of their respective warped surfaces. They pay no attention to the ratios between the diameters of their respective warped surfaces, to the extensions of these surfaces relative to each other with reference to their common longitudinal axis, and to the diameters of the exit holes of their outer warped surfaces. They do not block or reject spurious entry or exit non-paraxial rays. For these reasons and others, they do not produce a well defined beam.

SUMMARY OF THE INVENTION

The ray-concentrators of the present invention:

employ multiple reflection systems of paraxial rays between the inner surface of the outer paraboloid and the outer surface of the inner paraboloid;

utilize all paraxial rays emanating from a given source for maximum concentration into a well defined beam with an optimum ray gathering power;

block or reject spurious non-paraxial rays from degrading the well defined beam;

utilize also rays impinging against the center of the vertex of the inner shell;

provide for accurate adjustment of the spacing of the reflecting shells;

eliminate freqency and spherical aberrations.

Other objects and advantages of the system of the present invention will become apparent to those skilled in the art from the following description and claims and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional diagrammatic view showing the basic improvements of the invention over the prior art, common to the several preferred embodiments.

FIG. **2** is a view similar to that of FIG. **1**, showing as an additional attachment a third reflector with a light source.

FIG. **3** is a view similar to that of FIG. **1**, showing a tuning means usable also in conjunction with other embodiments described hereafter.

FIGS. **4A** to **4P** are sectional views showing how various paraboloidal, conical or flat mirrors and reflecting belts may be arranged to concentrate light.

FIG. **5A** is a sectional view in which a well defined incident beam is reflected from conical belts, and then onto a paraboloidal belt, and thence into the paraboloidal mirrors near the apex of the light concentrator.

FIG. **5B** is a sectional view showing a device in which light is concentrated by only two reflecting surfaces, the first being a conical belt and the second apex of a cone.

FIG. **6** is an expanded perspective view of a light concentrator using multiple sources and banks of flat mirrors for the outer surface and paraboloidal belts for the inner surface.

FIG. **7** is a cross-sectional view taken along the lines VII—VII of FIG. **6.**

FIG. **8** is a diagrammatic cross-sectional view illustrating the assymetric light distribution, when a non-paraxial beam impinges on the light concentrator.

FIG. **9** is a diagrammatic view of a pointing device of the present invention.

FIG. **10** is a diagrammatic sketch showing the development of control signals and data signals for the pointing device of FIG. **9.**

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The equivalent or common parts or symbols to the various figures of drawings are denoted identically.

There is shown on FIG. **1** a light concentrator of the present invention employing symmetrical warped surfaces, shown as two truncated paraboloids, mounted confocally; a larger outer paraboloid **11** is provided with an inner concave reflecting face and an orifice **28** in its vertex and the inner paraboloid **9** with an outer convex reflecting surface.

A wide source of rays, emanating paraxial rays in the axial direction of the two paraboloids, is shown in FIG. **1.**

An incident paraxial ray of light, after reflection from the large mirror, is directed toward the common focal point.

After reflection from the small mirror, this same ray is redirected to its original direction parallel, but closer, to the axis.

Thus, an incident paraxial ray moves stepwise toward the axis but never crosses it.

All paraxial light rays entering the annular area between the two mirrors are thus concentrated into the space between the two vertices. If there is a hole at the vertex of the large mirror, the light will emerge as a concentrated, well-defined beam of light.

A ray "A" coming from the source of rays "S" impinges upon the inner reflecting face of the outer paraboloid at point **13,** reflects from there as ray A_1 to impinge upon the outer reflecting face of the inner paraboloid at point **15**; from there is reflects as ray A_2 to the inner face of the outer paraboloid at point **19**; from there it reflects again as ray A_3 to impinge on the outer face of the inner paraboloid at point **21,** wherefrom again it reflects as ray A_4 to impinge on the inside of the outer paraboloid at point **23**; to return therefrom as ray A_5 to impinge upon the outer face of the inner paraboloid at point **25**; thence it again reflects as ray A_6 which is a component of the emergent beam **27.**

While FIG. **1** traces the travels of only a single ray "A" from the source, every additional paraxial ray such as B, C, and D shown in FIG. **1,** coming from the source S, impinges at various respective points of the outer and inner paraboloids and travels a path similar to that of the ray A.

After each reflection from the convex mirror of the inner paraboloid the ray is reflected again parallel to the axis.

The sum of all the rays A plus B etc. ultimately combines at the exit orifice **28** as a single well defined narrow high intensity beam **27**, combining the intensity of each component ray.

Conventional means are provided to mount the two paraboloids relative to each other.

The common focal point of the two paraboloids is an essential factor for the operability of the invention. Rays A, A_2, A_4 and A_6 (and the corresponding rays B, C, etc.) are parallel to the central axis and rays A_1, A_3, A_5 and the corresponding rays B, C etc. are directed toward the common focal point of the two paraboloids as indicated in the dotted line extension of ray A_1.

The parabolas shown in FIG. **1** represent the cross-sectional view of the two paraboloids in a section taken through the central axis. In polar coordinates with the origin of coordinates taken at the common focal point, these parabolas can be expressed as follows:

$$r_1 = \frac{2a}{1-\cos\phi} \text{ and } r_2 = \frac{2(a/4)}{1-\cos\phi}.$$

Referring to these equations, it is apparent that the points of intersection of a line from the focal point to the two parabolas are in a constant ratio independent of the angle ϕ. In FIG. **1** this ratio (outer parabola to inner parabola) is 4:1. A larger ratio reduces the number of reflections within the light concentrator but also increases the likelihood of extraneous non-paraxial rays reaching the exit orifice directly without reflection from either paraboloidal mirror. It is this ratio, together with the parameter a in the above equations, which determines the spacing between the two paraboloids. The vertices of the parabolas in FIG. **1**, for example, are separated by a distance of $3a/4$.

Should, however, the ratio be 1:1, the two paraboloids would coincide into one and defy their purposes.

Thus, FIG. **1** shows a multiple ray reflection arrangement of two paraboloids concentrating typical incident paraxial light rays into a single output beam. The intensity of the beam output equals the sum of intensities of the incident paraxial rays.

The diameter of the exit orifice at the vertex of the outer paraboloid is scaled to be sufficiently small in relation to other dimensions of the device

to eliminate passing therethrough of non-paraxial rays which otherwise would adversely affect the definition of the concentrated beam,

to guide the rays, including the limiting rays A impinging at the outermost diameter, through at least two reflections at the outer shell and the inner shell each.

The distribution of non-paraxial rays, if any, from the source impinging on the inner surface of the outer paraboloid is shown on FIG. **8.**

Specifically, FIG. **8** shows that non-paraxial rays tend to be rejected by the light concentrator and that the manner of rejection depends on whether the incident ray makes a positive or negative angle, $\pm\delta$, with the central axis. FIG. **8** also shows that an incident, well-defined but non-paraxial beam of light produces an assymetric distribution of light within the concentrator. The embodiment shown in FIGS. **9** and **10** makes use of this feature.

A cylindrical baffle **29** may be attached with its periphery to the periphery of the outer shell to block outside dispersed rays.

As can be seen from FIG. **1**, the incident parallel ray "A" is a limiting ray. Rays at a distance from the axis greater than shown are not gathered by the light concentrator. This limiting ray is reflected at the extremity of each of the paraboloids and, if extended beyond the inner paraboloid, would intersect the central axis at the common focal point making an angle ϕ_1 with the central axis. Thus, it is unnecessary and, in fact, wasteful to have either paraboloid extend beyond the limiting ray. If the outer paraboloid should be so extended, the additional rays that are gathered would not strike the inner paraboloid and so would be wasted. If the inner paraboloid should be so extended, it would gather no more rays but would create additional blocking of incident rays thus reducing the ray gathering capability of the concentrator. The extremities of the outer and inner paraboloids should lie on an imaginary cone whose apex is at the common focal point.

The cross-sectional area of the annular space between the two paraboloids, i.e. the portion available to collect paraxial rays, is a measure of the light gathering power of the light concentrator. The ray gathering capacity can be increased by increasing the parameter a used to determine the form of the paraboloids. This method increases the diameter of the concentrator but causes only a small increase in length. It is a simple change of scale.

The ray gathering capacity may also be increased by extending the two paraboloids while maintaining the condition that their extremities must lie on an imaginary cone whose apex is at the common focal point. This second method increases both the diameter and the length of the concentrator. An increase in the length of the concentrator, as in the second method mentioned above, results in additional reflections of incident paraxial rays. Because of the effect of such reflections on non-paraxial rays, shown on FIG. **8**, the emergent beam from a longer concentrator would tend to have less divergence than a beam from a shorter concentrator.

The multiple reflections within the concentrator of the invention have the effects of:

1. concentrating incident paraxial rays into an intense emergent beam;

2. removing divergent rays from the emergent beam so that it is well defined; and

3. creating an assymetric distribution of rays within the concentrator when a non-paraxial incident beam is present.

The degree of concentration of light achieved by the invention will depend on the type and number of sources used, the size of the exit orifice, and other dimensions. For the particular case for which each shell is a continuous paraboloidal mirror and for which the source of light is broadly dispersed, a concentration factor, defined as the cross-sectional area perpendicular to the central axis and available to gather light divided by the cross-sectional area of the exit orifice, can be calculated as follows:

$$\text{Concentration factor} = \frac{16}{\tan^2\frac{\phi_1}{2}} \cdot \frac{a^2}{d^2} \cdot \frac{R^2-1}{R^2}$$

where

ϕ_1 as shown in FIG. 1 is the angle made with the central axis

by the inwardly directed limiting ray A_1,

a is the parameter determining the form of the paraboloids,

R is the ratio of the dimension of the outer paraboloid to that of the inner paraboloid,

and d is the diameter of the exit orifice.

The concentration factor will be increased by increasing a or R or by decreasing ϕ_1 or d. In general, as the concentration factor increases so also does the number of reflections required for a ray to transit the device, except that increasing R will decrease the number of reflections required. To achieve the condition that the limiting ray A impinging at the outermost diameter undergoes at least two reflections at each shell as it transits the device, the ratio of the diameter of the exit orifice to the outermost diameter must be less than $1/R^2$, to achieve at least three reflections at each shell this ratio must be less than $1/R^3$; etc. The source of rays may be optical, such as the sun, day-light, incandescent or fluorescent lights, infra red or ultraviolet light, radar, laser, acoustic, or other wave emanations. The rays may be emanating from a single source or from a plurality of sources continuously, occasionally or in succession. Optionally, the inner paraboloid **9** is developed as a one-way mirror, with mirror reflection from the convex side. The one-way mirror is a conventional transparent material using thin film coatings or a polarized mirror permitting passing of rays, in this instance, only in the direction toward the exit orifice.

A practical embodiment of the concentrator of FIG. 1 is demonstrated in FIG. **2.**

To the periphery **15** of the inner truncated paraboloid **9** an elongated shaft **33** is attached fixedly and disengagingly to extend axially in the direction opposite from the vertex of the inner paraboloid.

A second outer truncated doughnut-shaped paraboloid **31** having a diameter of its outer periphery **13***a* same as that of the first outer paraboloid and the diameter of the inner periphery **15***a* matching with the periphery of the shaft **33** is mounted fixedly and disengagingly with its respective peripheries to the periphery **13** of the outer paraboloid **11** and to the periphery **35** of the shaft.

The concave surfaces of the two outer paraboloids together with a portion of the cylindrical surface of the shaft and the convex surface of the inner paraboloid thus form a symmetrical fully enclosed housing.

A conventional source of rays S is mounted at the focal point of the second outer paraboloid, located as to maximize the amount of parallel rays incident on the concentrator. The source is a ring tube fixture **37** of a shape such as a common fluorescent light tube. The tube is arranged so that the resulting rays enter paraxially into the annular space between paraboloid **11** and paraboloid **9.** Conventional means to mount the ring tube into the focal circle of the second outer paraboloid are provided.

The shaft, in addition to its function as a central cylindrical wall of the housing, functions also as a means for mounting together the paraboloids and provides a housing for an external power supply or a battery, or for accessories for a mercury arc, laser gun or other ray sources. It also serves as a handle for a portable device or as a means for fixedly mounting the device.

FIG. **3** depicts an application of the concentrator of FIG. **1** to a dispersed source of rays, such as the sun. To the periphery **15** of the inner paraboloid **9** is joined a cylindrical shaft **33** extending axially rearward.

Preferably the shaft diameter is slightly less than that of the inner paraboloid so that it does not obstruct incident light.

Between the periphery **13** of the outer paraboloid and the periphery **35** of the shaft is mounted a transparent annular cover **41,** preferably planar, provided at its inner ring periphery **47** with means to adjust the spacing of the two paraboloids. Such means, as an example, are a threaded sleeve **43** attached to the inner pheriphery **47** of the transparent cover **41** and a threaded section **45** of the shaft **33.** The threaded portions thereby also provide means of joining the inner paraboloid with the cover and through it also with the outer paraboloid.

Thus, the transparent cover and its threaded sleeve together with the threaded shaft provide a convenient method for assembling the light concentrator. By turning the threaded shaft, the inner paraboloid can be moved in or out for tuning to achieve the criterion of a common focal point and the resulting well-defined emergent beam.

In the embodiment shown on FIG. **1,** the reflectors are shown as reflecting, continuous paraboloidal surfaces. For better performance in specific applications, these surfaces are segmented, at least in portions, into a plurality of spaced reflecting surfaces, developed either as paraboloidal belt sectors, or truncated cone belt sectors or banks of mirros, either as concave/convex or flat segments.

The source of rays which impinge on these various types of reflecting surfaces may be a single continuous source comprising paraxial rays only, or a mixture of paraxial rays with non-paraxial dispersed rays, or a plurality of spaced sources of oriented paraxial rays.

In accordance with the sources available or provided, the concentrator may be developed in all available mathematical variations and combinations of these sets of given basic elements.

FIGS. **4A** to **4P** show some of these various preferred combinations. Throughout FIGS. **4A** to **4P,** the designations **11** and **9** refer to the basic paraboloidal reflecting surfaces which in some cases occur only at the vertices; **11***a* and **9***a* are reflecting paraboloidal belts; **11***b* and **9***b* are reflecting conical belts; and **11***c* and **9***c* are flat mirrors.

In all of the examples shown in FIGS. **4A** to **4O,** the incident light is shown as a paraxial ray. In some embodiments, such as shown in FIGS. **6** and **7,** where, for instance, multiple laser sources are usable, it may be inconvenient or impossible to arrange all of the laser sources into the space available. In such situations, the laser sources may be spread out into a larger space and oriented so that their individual beams are somewhat convergent (non-paraxial). Then by using conical belt mirrors or flat mirrors properly oriented, these individual beams may be converted to paraxial beams after the second reflection. FIG. **4P** illustrates this and the principal is applicable to other embodiments as in FIGS. **5A, 5B, 6** and **7.**

FIG. **5A** shows, as an example, an embodiment of the concentrator in which well defined incident rays are reflected from a bank of conical parallel spaced reflector

belts 11*a*, 11*b* etc of the outer shell 11 upon an inner paraboloidal reflector belt 9*a* of the inner shell 9.

The reflecting surfaces 11 and 9 near the apex of the light concentrator shown in FIG. 5*a* are both of true paraboloidal shape. This, together with the paraboloidal belt 9*a*, permits utilizing the property of such paraboloids of rejection non-paraxial rays.

Means are provided for supporting the reflector segments.

The belt reflectors may be provided, f.i. directly in the outer and inner reflector shells and the non-reflecting spaces blackened out, or they can be supported by external structures.

The source provides narrow rings of rays with appropriate radii. Appropriate for this purpose would be a plurality of laser sources arranged in such rings. Any of the presently available solid-state lasers, semiconductor diode lasers, or gas lasers, such as described f.i. in Laser Technology and Application by Samuel L. Marshall, McGraw-Hill Inc., 1968, could be used.

In this embodiment of the concentrator there is a minimum loss of the power of the emitted rays, since the light source is directional, and a well defined beam is obtained. As an alternative, the reflector belts 11*a*, 11*b*, etc of FIG. 5A may be paraboloidal belts.

There are depicted preferred variations of the device as follows:

In FIG. 4A showing the inner reflecting surface of the outer concave shell the outer reflecting surface of the inner shell being paraboloids.

In FIG. 4B showing the inner reflecting surface of the outer shell comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally, the outer reflecting surface being a paraboloid.

In FIG. 4C, showing the inner reflecting surface comprising a paraboloid at the vertex and a conical belt spaced therefrom coaxially, the outer reflecting surface being a paraboloid.

In FIG. 4D, with the inner reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom, the outer reflecting surface being a paraboloid.

In FIG. 4E, the inner reflecting surface being a paraboloid, the outer reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally therewith.

In FIG. 4F, the inner reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally therewith, and the outer reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally therewith.

In FIG. 4G, the inner reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially, the outer reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally.

In FIG. 4H, the inner reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom, the outer reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally.

In FIG. 4I, the inner reflecting surface being a paraboloid, the outer reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially.

In FIG. 4J, the inner reflecting surface comprising a paraboloid at the vertex and at least one paraboloidal belt spaced therefrom confocally, the outer reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially.

In FIG. 4K, the inner reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially, the outer reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially.

In FIG. 4L, the inner reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom, the outer reflecting surface comprising a paraboloid at the vertex and at least one conical belt spaced therefrom coaxially.

In FIG. 4M, the inner reflecting surface being a paraboloid, the outer reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom.

In FIG. 4N, the inner reflecting surface comprising a paraboloid at the vertex and at least one paraboloid belt spaced therefrom confocally, the outer reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom.

In FIG. 4O, the inner reflecting surface comprising paraboloid at the vertex and at least one conical belt spaced therefrom coaxially, the outer reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom.

In FIG. 4P, the inner reflecting surface comprising a paraboloid at the vertex and at least one flat mirror spaced therefrom, and the outer reflecting surface comprising a paraboloid at the vertex, at least one flat mirror spaced therefrom.

In FIG. 5B, an additional variation is shown in which the reflecting surface of the inner shell is reduced to a minimum until it forms only the apex of a reflector cone avoiding all parabolic surfaces.

The object thereof is to eliminate all reflections after the second. By shrinking the diameter of the inner reflective surface, a reasonably small emergent beam is obtained and the losses inherent in subsequent reflections are avoided. This has the advantage of improving the efficiency of the concentrator and is simpler in that it need not involve any paraboloidal surfaces.

FIGS. 6 and 7 show an embodiment of the concentrator which avoids the general requirement that the incident rays be directed parallel to the axis and employs multiple spaced sources of rays.

The embodiment of FIGS. 6 and 7 is developed as an example of a concentrator using as the source of rays laser beams, which emanate from various angles and locations, most suitable for their installation and whereby the incident rays are not necessarily parallel to the axis. The reflecting surfaces are adjusted accordingly.

The reflectors of the outer concave shell are in banks of flat mirrors such as 13A, 13B, 13C, 13D, etc. with a paraboloidal mirror at the vertex.

The reflectors of the inner convex shell are spaced paraboloidal belt sectors 15A and 15B, with a paraboloidal mirror at the vertex. Both the convex and concave shells are arranged toward a common focal point of the imaginary two paraboloid shells. Imaginary extensions of the rays reflected inwardly converge toward the common focal point.

The source beams are oriented selectively in such directions that they hit the flats such as **13A**, **13B** and are then reflected toward the common focal point. Thus, each flat is optically connected with a laser source. In addition to the flats shown by way of example, a whole series of them may be arranged geometrically spaced, preferably symmetrically, so that they do not present obstacles to the incident or reflected rays. The paraboloidal reflecting surfaces in this embodiment, in addition to concentrating the light, serve to improve the definition of the emergent beam. The inner paraboloid developed as a one-way mirror described with reference to FIG. **1** may be employed also in conjunction with the embodiments shown on FIGS. **3**, **4**A to P, **5**A, and **6** and **7**.

FIG. **9** shows another embodiment of the concentrator of the present invention developed as a pointing device to point the concentrator accurately at a distant source, f.i. for astronomical scanning. It may also be used for coded ship to ship or shore signalling. The outer concave reflector shell **11** and the inner convex reflector **9**, each are shown developed as truncated concave paraboloids.

The outer paraboloid is equipped with five symmetrically spaced apertures (not shown in FIG. **9**), one of which is centered. A detector such as a photocell **130**, 132, 133, 134 and **136** is provided as a monitor for each aperture.

The pointing device is provided with a vertical drive unit **16** and is suspended in a gimbal suspension for universal limited movements in cartesian coordinates. Drive means are also provided for a horizontal drive.

Because non-paraxial rays are affected differently by the light concentrator depending on whether the angle they make with the axis is positive or negative (see FIG. **8**), the light concentrator can be used as device for maintaining direction relative to a distant source of light, such as the Moon. If the light concentrator is not pointed correctly, the Moon's light will not be parallel to the axis and the distribution of light within the concentrator will be assymetric about the axis. The different intensities of light emerging from the several apertures are compared to develop control signals to point the light concentrator at the source. When pointed so that the axis is parallel to the Moon's rays, there is complete symmetry, the control signals are zero, and the central signal then is at a maximum.

If the distant source is a transmitting station sending coded signals on a beam of light, then the output of the five detectors may be combined and sent to a conventional network for receiving and interpreting the signals.

FIG. **10** shows as an example how the control signals and data signals can be developed. The techniques are essentially the same as those used by V. F. Pizzuro et al in U.S. Pat. No. 3,504,182.

Four detectors **130**, **132**, **134** and **136** are interconnected by coupling networks **140**, **142**, **144**, **146**. Turning attention first to coupling networks **140**, it may be seen that this comprises a center-tapped resistance having its output wire connected as one input to a vertical differential amplifier **150**, whose output is applied to the vertical drive unit **16**. Coupling network **144** also comprises a center-tapped resistance having its output wire connected as another input to vertical differential amplifier **150**. Coupling networks **142** and **146** are similarly constructed, and similarly connected to a horizontal differential amplifier **152**, whose output is applied to the horizontal drive unit.

Network **148** sums the signals of the five detectors and applies the sum as an input to the Data Receiver.

The central exit orifice of each of the various embodiments shown may be provided with a conventional photo lens diaphragm, and means for controlling its diameter **28***a*, manually or automatically, connected with an optical sensing system **133** analogous to that shown on FIGS. **9** and **10** and/or interconnected with a tuning system **43**/45 such as shown on FIG. **3**.

USES OF THE LIGHT CONCENTRATOR

In some applications it is desirable to design a well defined and narrow beam of light to establish a precise line in space; for instance, as a navigation signalling aid or as a tool in surveying work. Assume an observer sights the beam by looking toward the source while many yards away from the source. The precision with which one can thereby determine his direction from the source depends on the width of the beam. To achieve a very narrow beam and thereby a greater precision, it is desirable to eliminate divergent rays from the beam even at the loss of some intensity. A light concentrator similar to that shown in FIG. **2** would achieve this. So also would a light concentrator similar to any of the variations discussed in connection with FIG. **4**.

Aside from the obvious purpose of increasing the intensity of the resultant beam, the light concentrator with multiple laser sources may have applications in communications. For example, the second, third, etc. laser sources may be redundant serving as standby sources in case of failure of the primary source. Or, the different sources may be such that they produce different frequencies to permit a rapid shift from one frequency to another. In the latter case the multiple frequencies may be combined in the common output beam for increased data handling capability.

Because a laser source produces a discrete beam, it is not necessary that the reflecting mirrors form complete belts as in FIG. **5**A. This is particularly true of the outermost mirror **11***a*, which produces the first reflection. Here, where the dimensions are largest, it is logical to replace the belt mirror with small segments that are truly flat — each segment being aligned appropriately with its own laser source. Thus, it is possible to install two or more rings of laser sources, each source directing its beam to its own allocated mirror for the first reflection. The arrangement of each source and its mirror is such that there is no obstructing of other ray emissions.

The plurality of sources of rays depicted on FIGS. **6** and **7** with the individual reflectors for each source, offer a multiplicity of possibilities to concentrate rays of various characters such as of different intensities, frequencies, or phase differences and to utilize them for optimum desired effects.

The plurality of sources may be occupied by a source of rays of the same or of different types and they may be fired simultaneously or selectively, continuously or in timed and/or spaced successions. A pulsed emission has utility in laser systems. As an example, laser beams emanating from a ruby rod are limited in intensity to the useful length of the ruby rod; the ruby rods, being expensive and breakable, cannot be utilized advantageously beyond certain lengths which are not great enough to produce the required intensities.

In accordance with the invention, a plurality of ruby rods each having a below critical length can be substituted in the embodiment described on FIGS. 6 and 7 to produce a laser beam of any desired intensity.

CO_2, or other laser sources, may be combined with ruby rods as the sources of improved laser beams.

Light sources of various colors may be combined in the present invention for desired purposes. Infra red light sources may be mixed, f.i. with ultra violet sources into combination beams of predetermined qualities and quantities.

Laser sources that produce beams of relatively poor definition, such as semi-conductor diode lasers, may be used with the embodiment of FIG. 5A or of FIGS. 6 and 7 to produce an output beam of much higher quality.

In summary, some of the possible applications are:

1. For concentrating the sun's rays to kindle a fire, to heat an object, or to provide thermal energy for conversion into electrical energy.

2. For special lighting effects in artistic or theatrical displays.

3. For any purpose needing a well defined beam. In many applications where coherence is not essential, this device might replace laser devices at lower cost, for example as a navigational aid or a surveying tool.

4. For pointing. Because the device is highly selective of paraxial light, it may be useful for pointing at a distant light source. In particular, it may have such applications in surveying work and in space communications.

5. For an improved laser system.

6. For communication combining radiations of various types into a common beam for redundancey, rapid change of frequency, or increased data rate.

For claim purposes, the following definitions are employed:

"Source" defines electro-magnetic waves in all spectra, including light rays, infra red rays, ultra violet rays, laser rays, sound waves, and other types of radiant energy emissions including electrons, in short any emissions which can be reflected.

"Shells" define symmetric or assymetric continous surface structures and segments thereof, warped or flat, including rings or belts and flats.

While the above disclosure describes and illustrates only selected forms of the invention, it is to be understood that the same may be varied, within the scope of the appended claims, without departing from the spirit of the invention.

I claim:

1. A concentrator of rays into at least one concentrated output beam, comprising:

at least two warped truncated shells, including an outer concave shell, provided with at least one inner reflecting surface and

an inner convex paraboloidal shell of a diameter, smaller than that of said outer shell provided with at least one outer reflecting surface;

means to mount said shells about the common focal point on their central axis;

the extremities of said shells being aligned on a conical surface and being defined by an imaginary cone whose surface is traversed by the limiting rays and whose vertex is at the common focal point, and whose axis coincides with the central axis,

said extremities defining the limiting rays impinging upon said reflecting surfaces;

an exit orifice in the vertex of said outer shell at the intersection with the said central axis;

the reflecting surfaces of the shells being mounted spaced from each other and substantially facing each other at angles and at distances providing at least two successive reflections from each surface of said rays impinging upon them;

the ratio of the diameter of the exit orifice to the outermost diameter of the outer shell being less than $1/R^2$ where R is the ratio of the dimension of the outer shell to that of the inner shell and

at least one radiating source of paraxial rays located rearwardly from the concentrator, the vertex of the inner shell being a one way mirror.

2. A concentrator of rays as claimed in claim **1**, at least one of said reflecting surfaces including at least one paraboloidal reflector.

3. A concentrator of rays as claimed in claim **1**, the inner reflecting surface of the outer concave shell and the outer reflecting surface of the inner shell being paraboloids.

4. A light concentrator as claimed in claim **1** and means to mount the reflecting surfaces of said outer and inner shells fixedly relative to each other.

5. A concentrator of rays as claimed in claim **1**, further comprising a housing extending rearwardly axially from the vertex of said inner shell for accessories of the power supply, functioning simultaneously as a handle.

6. A concentrator of rays as claimed in claim **1**, further comprising a shaft extending rearwardly axially from the vertex of said inner shell, said shaft to serve as a handle or mounting means for said concentrator.

7. A light concentrator as claimed in claim **1**, further comprising an outer truncated, toroidal paraboloidal shell with a concave reflecting surface, the outer periphery of said toroidal shell mating with the periphery of said outer shell, the inner periphery of said toroidal shell extending into a mating contact with the periphery of said inner shell, said source of rays being a ring-like source, means to mount said ring-like source in the focal ring of said toroidal shell, and means to mount said toroidal shell to said outer and inner shells fixedly and disengagingly.

8. A light concentrator as claimed in claim 7 further comprising a central elongated shaft extending from the periphery of said inner shell axially away from its vertex, the inner periphery of said toroidal shell coinciding with the periphery of said shaft and means to assemble it with said shaft.

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