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(54) CYLINDRICAL SOLAR ENERGY COLLECTOR

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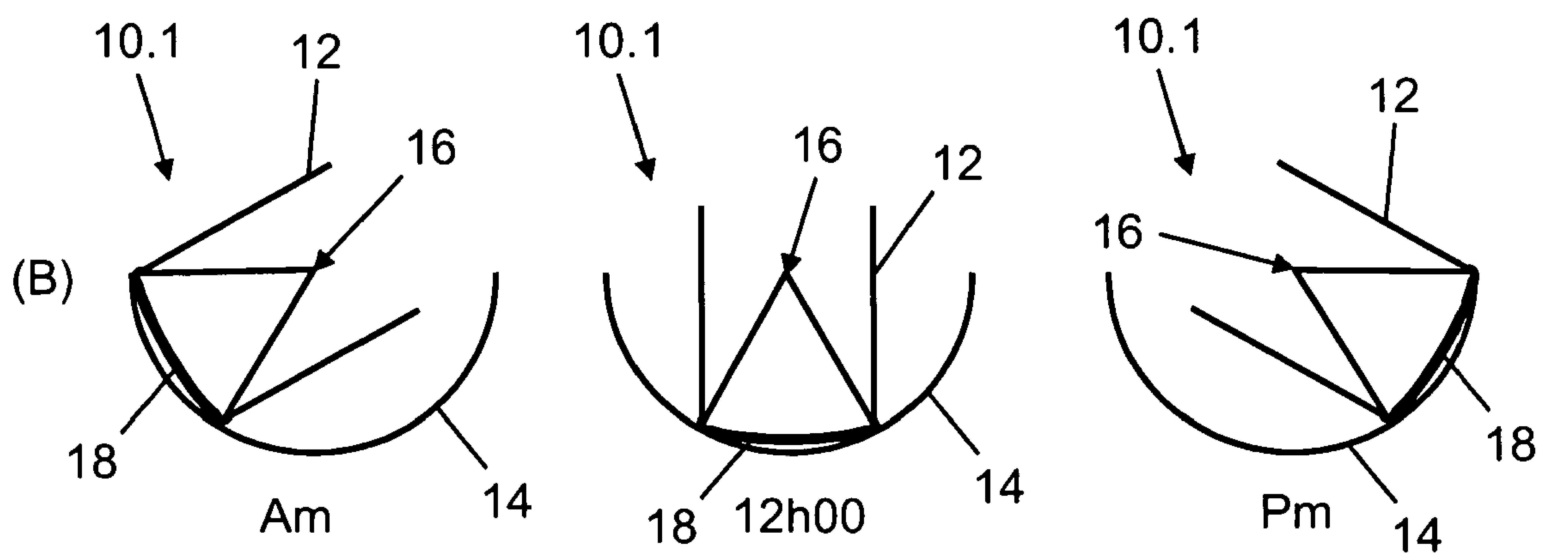
(57) **ABSTRACT**

A system is disclosed to employ optical collectors **10** including cylindrical troughs **14** below ground level for solar-thermal generation of electricity. In one preferred embodiment, the interior wall **24** of the cylindrical trough **14** is coated with reflective material to act as primary cylindrical collector mirror **20**. Since the trough **14** is situated in the ground, this mirror **20** can be very large and large concentrated power densities can be obtained. A set of corrector mirrors **28** in a relative small boxlike structure **22** focus all rays on a receiver tube **16** situated at the center of curvature of the trough **14**. The tracking of the sun is achieved by rotating this collector box **22** in the trough **14** about the center of curvature. No movement of large mirrors is required since the large primary mirror **20** is fixed and the corrector mirrors **28** in the corrector box **22** are relatively small. The collector **10** can also be used as concentrator for photovoltaic cells or it can be used for water heating.



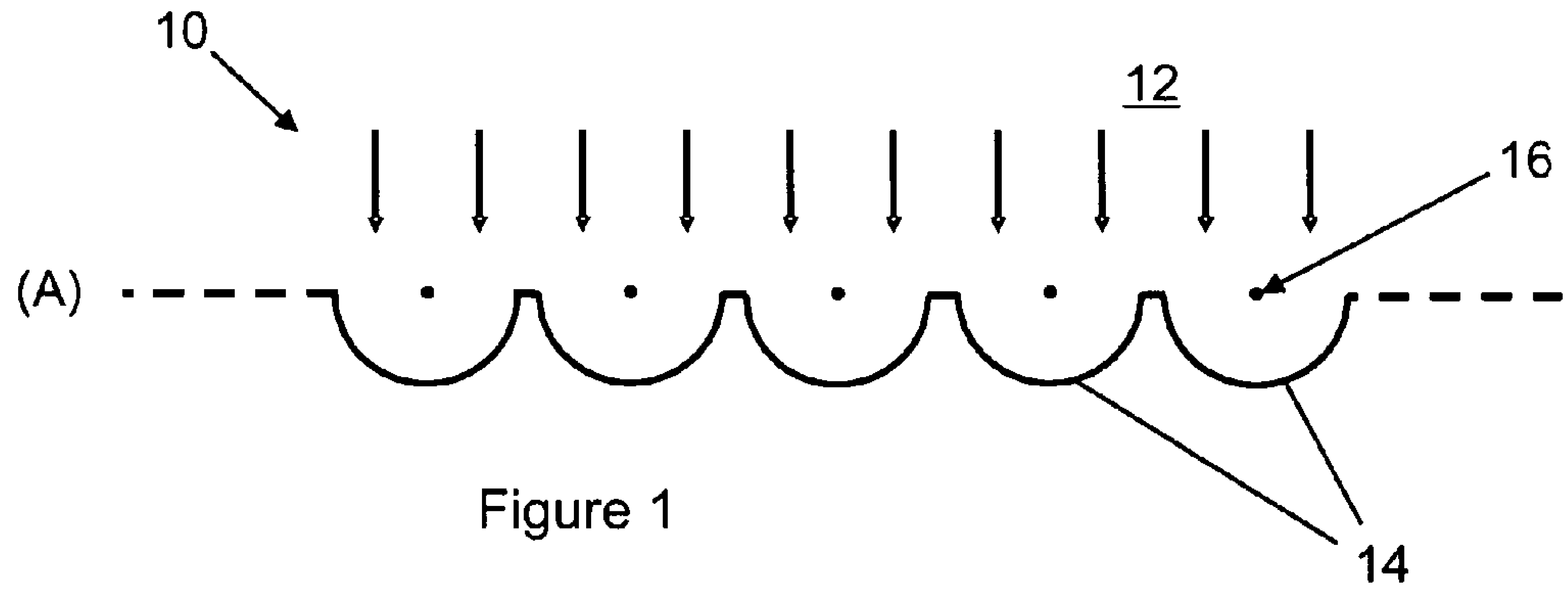


Figure 1

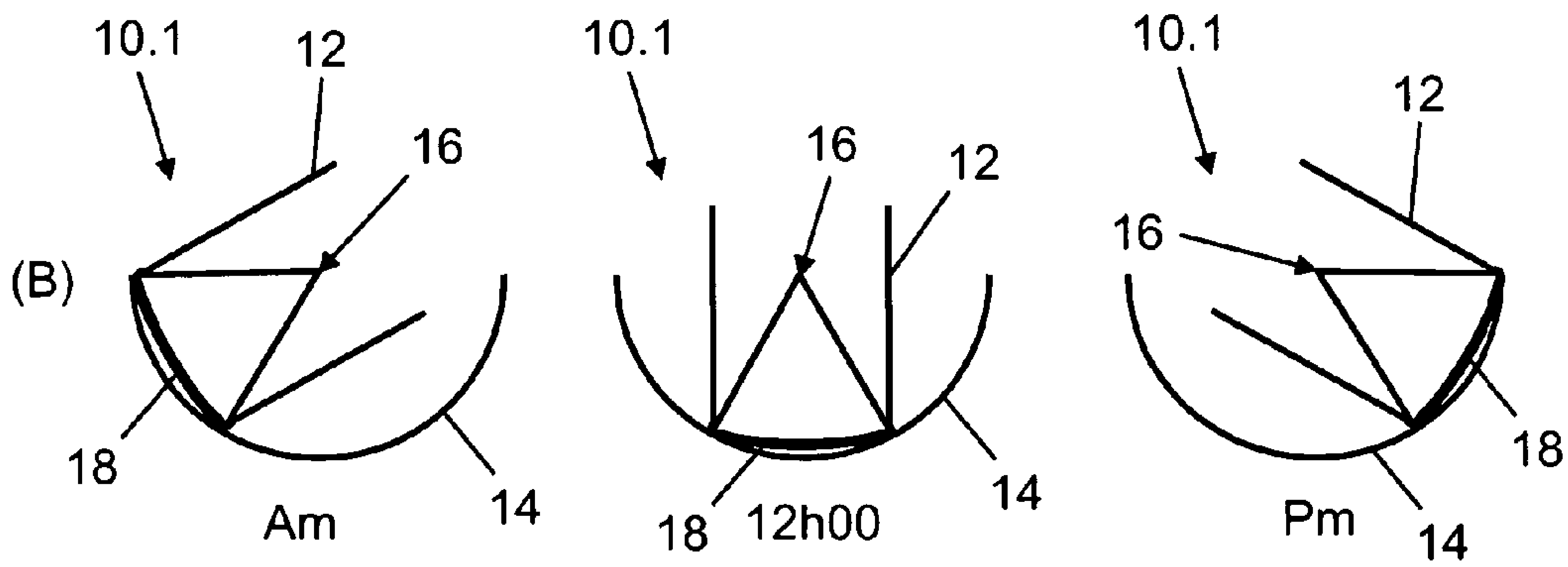


Figure 2

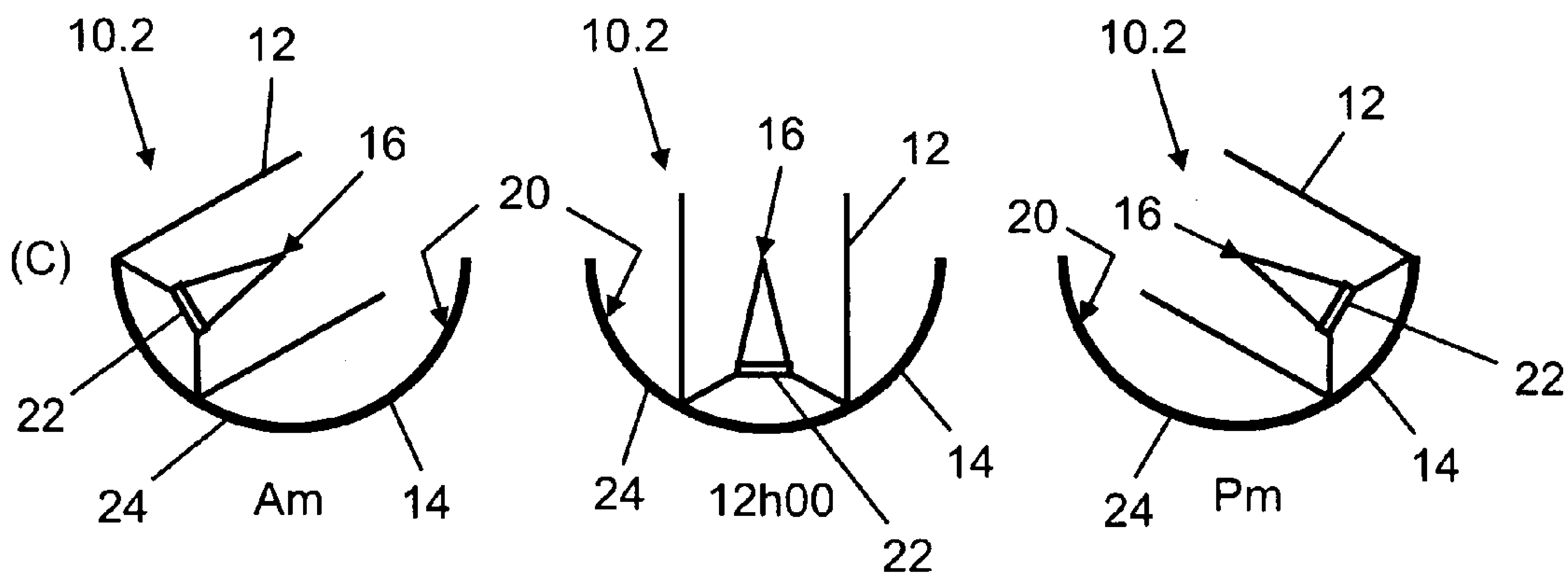


Figure 3

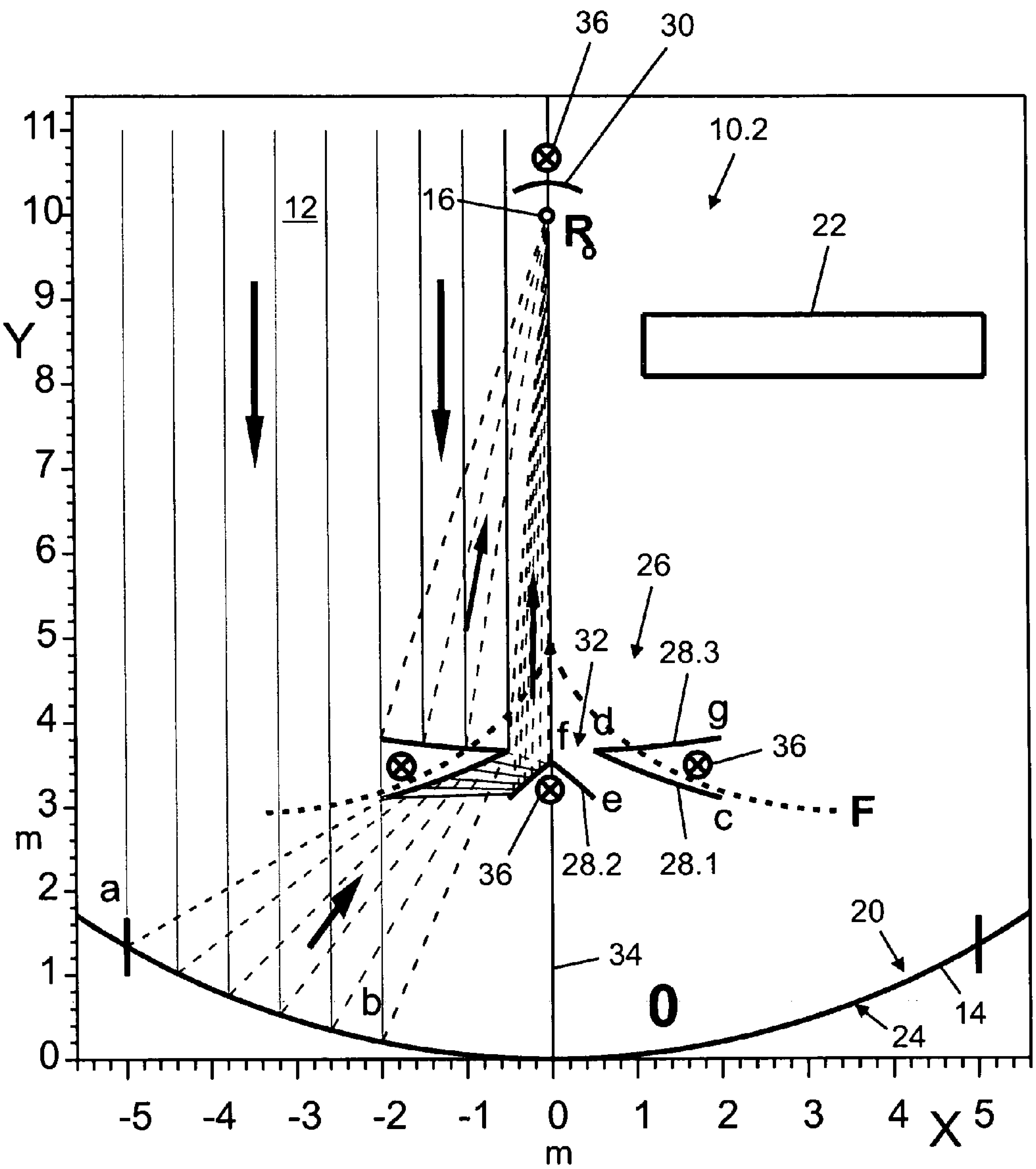

36
30
10.2
12
16
R
o
22
Y
26
32
28.3
d
g
f
36
e
F
c
m
36
28.2
28.1
a
20
34
b
0
14
24
-5
-4
-3
-2
-1
0
1
2
3
4
5
X
m
0
1
2
3
4
5
6
7
8
9
10
11

Figure 4

	a	b	c	d	e	f	g	d
X	-5.000	-2.000	2.000	0.500	0.500	0.000	2.000	0.500
Y	1.340	0.202	3.091	3.654	3.091	3.520	3.801	3.654
Width	3.21		1.60		0.66		1.51	

Figure 5

	R	XO	YO
28.1	8.500	4.225	11.294
28.2	4.644	-2.766	-0.210
28.3	12.871	0.000	16.516
30	0.800	0.000	9.575

Figure 6

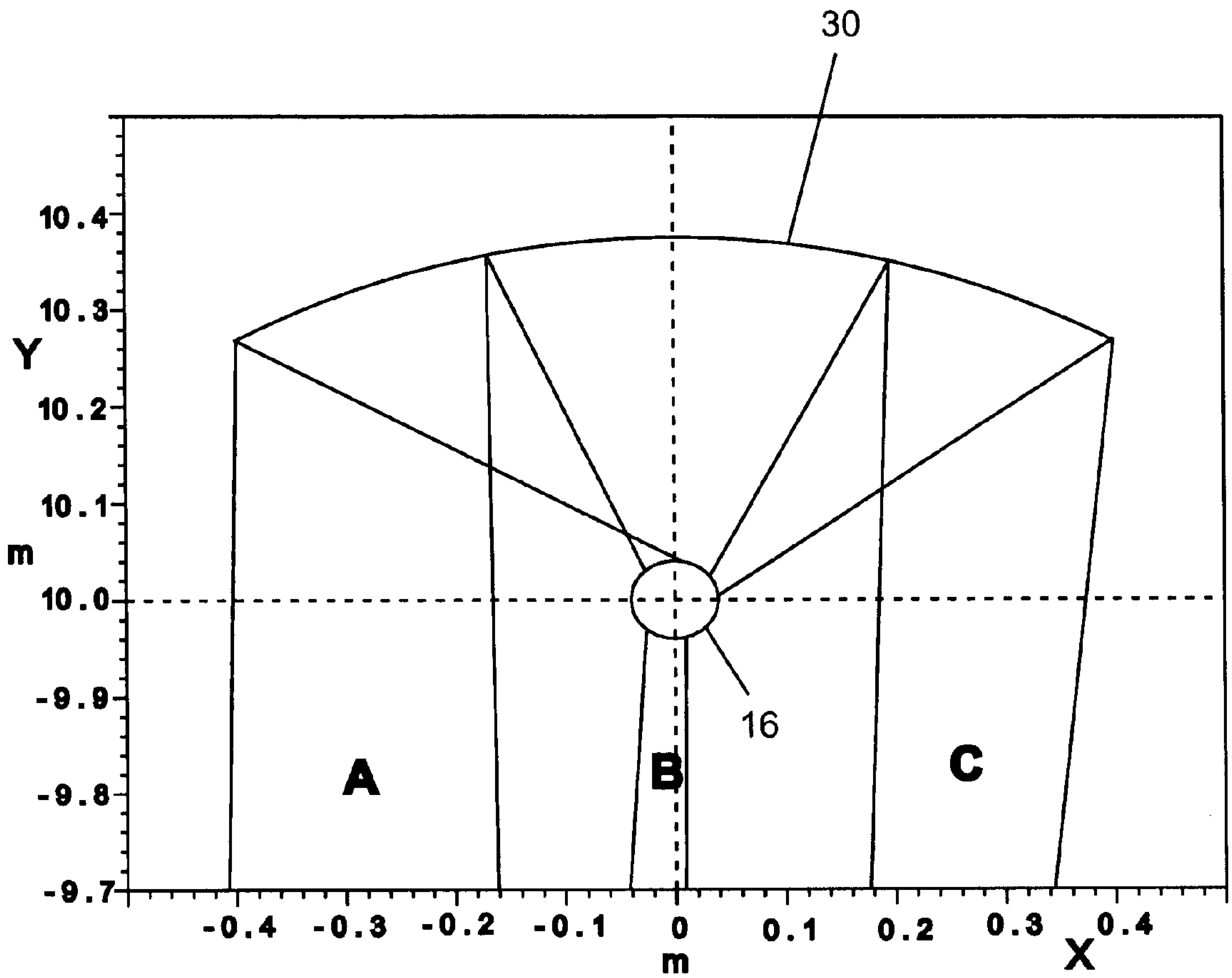


Figure 7

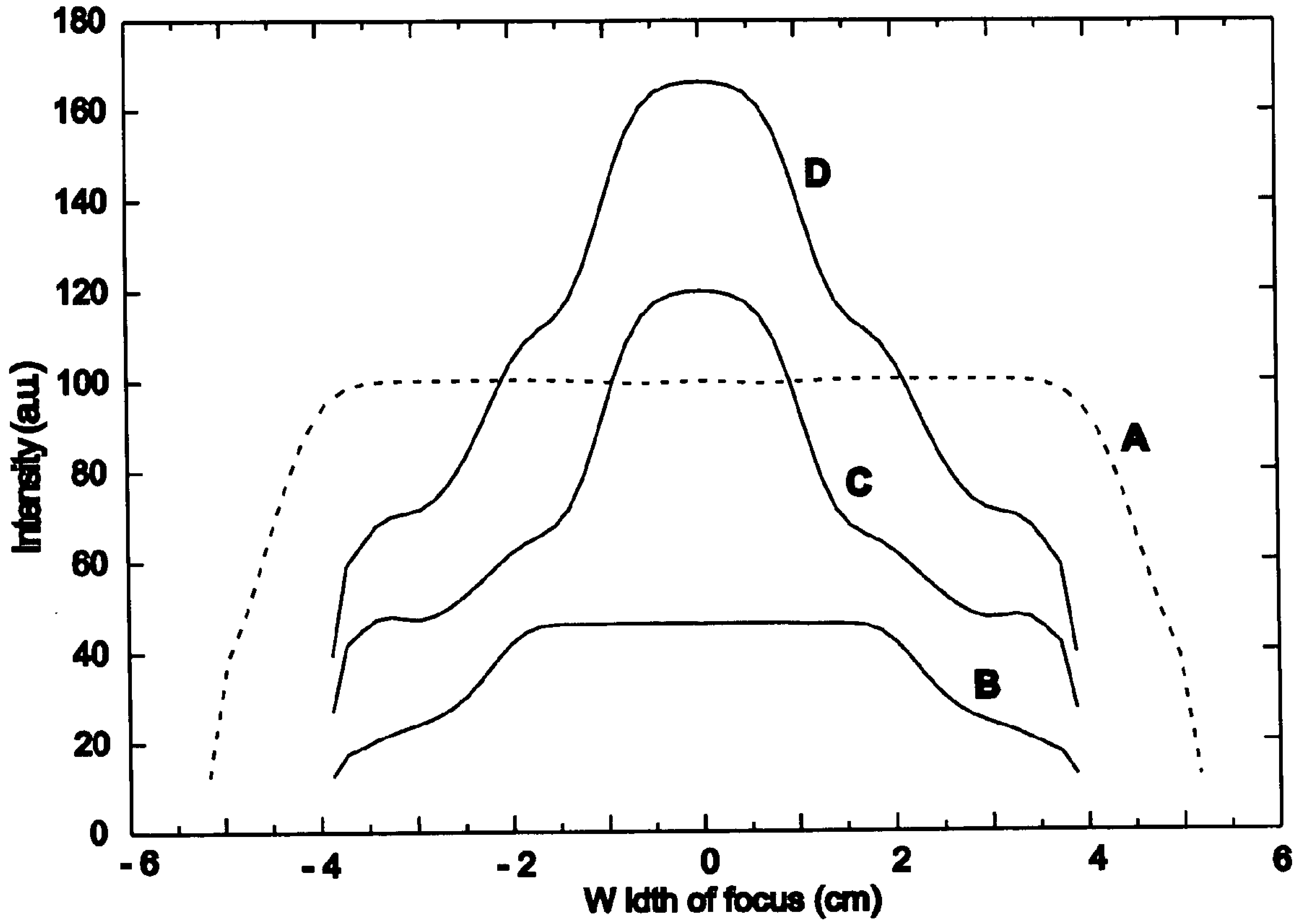

180
160
140
120
100
80
60
40
20
0
Intensity (a.u.)
-6
-4
-2
0
2
4
6
W idth of focus (cm)
D
C
A
B

Figure 8

CYLINDRICAL SOLAR ENERGY COLLECTOR

FIELD OF THE INVENTION

[0001] THIS INVENTION relates to solar-thermal generation of electricity. In particular, the invention relates to a cylindrical collector system for large scale generation of electricity.

BACKGROUND TO THE INVENTION

[0002] Limited progress was made up to now with the introduction of renewable energy sources on a significant scale to the energy supply of the world. Only renewable sources that present the possibility to be exploited on a very large scale will make a significant impact. The introduction of biomass and bio-fuels on a large scale is an obvious candidate since it requires no new sophisticated technologies and does not disturb the ecological balance in Nature. An urgent immediate task is to introduce a technology for the large-scale generation of electricity using renewable energy sources since the present socioeconomic condition in the world is dependent on the availability of electricity. Fossil fuel fired power stations are large contributors to Green House gasses and pollution in the atmosphere and public resistance towards the use of nuclear energy will not go away.

[0003] The most attractive renewable energy sources for the generation of electricity are geothermal energy and natural hydro energy. These two sources can however only be exploited where they are geographically available. The same applies to a lesser extent to tidal energy and wave energy. The construction of large new dams for hydro electricity however leads to other environmental and socio-economic problems.

[0004] The use of large wind generators in the MW range is already a mature technology and it is widely used. It is however only a viable option in geographical regions that have sufficient amounts of sustainable wind power. There is however an environmental problem associated with the introduction of large wind turbines: The public does not find it acceptable to have thousands of these large structures introduced into a pristine environment.

[0005] The use of the sun's radiation is the most appropriate source of energy for the large-scale generation of electricity. It is however only available during less than half of a typical day and technologies for the storage of energy will have to be developed. The total amount of energy that reaches the earth from the sun is 10000 times more than the present daily energy demand of the world, but this power is diffuse (less than 1 kW/m^2) and very large areas of collection will be required.

[0006] Two technologies are presently employed to generate electricity directly from sunlight: photovoltaics (PV) and solar-thermal generation. The use of PV is the most attractive option since in involves very little infrastructure and requires almost no maintenance. With the present high-tech manufacturing processes of PV cells and conversion efficiencies around 15%, PV remains a very expensive technology. Unless the PV cell technology can be simplified and the cost drastically reduced, flat plate PV will generally only be economically viable for remote applications and medium size electricity plants. The use of concentrators can however reduce the cost of PV. Solar-thermal generation of electricity on the other hand does not require high tech manufacturing processes and innovative concentrator technologies can increase the system efficiency and reduce the cost.

[0007] Solar-thermal generation of electricity employs the same energy conversion technology as that used in fossil fuel or nuclear power plants. The radiation of the sun is however used as source of energy to heat steam or a gas to a high temperature to drive the turbines. The total solar-to-electric conversion efficiency is in most cases not much larger than that of PV but the technology for the collection of the thermal energy is not high tech. The system requires a collector to collect the radiation and a receiver that absorbs the energy in a heat transfer fluid. To obtain a reasonable thermodynamic efficiency the temperature of the fluid must be high and this requires concentration of the solar radiation. The solar flux reaches the earth in a cone within a solid angle of about 0.532° and the maximum theoretical concentration for two-dimensional concentration is about 46 000 and for linear concentration about 215. To achieve a high concentration a large rim angle is required and the collector must be very large. In practice the concentration is lower than the theoretical limit due to geometric constraints and imperfections.

[0008] Present Solar-thermal electricity systems can broadly be classified into four types: Parabolic Dish, Central Receiver, Parabolic Trough and Linear Fresnel Reflector technologies.

[0009] The collector of a Parabolic Dish system consists of a large parabolic dish containing parabolic reflectors that concentrate the sunlight on a receiver at the focal point of the dish. Due to the two-dimensional concentration, concentrations are typically between 600 and 2000 and temperatures in excess of 1500° C. can be obtained. Relatively high thermodynamic conversion efficiencies are possible at these high temperatures. The conversion can be performed by mounting a Stirling engine at the focal point. The solar-to-electric conversion efficiency can be as high as 50% for these systems. The size of the receiver dish can however not be increased beyond practical limits since the structure has to withstand adverse weather conditions. The electrical outputs of these systems are usually around 10 kWe. The cost of these systems is very high.

[0010] Central Receiver systems employ a large number of heliostats that can be individually focused on a central receiver on top of a tower. Various types of arrangements of the heliostats around the tower are possible. Practical considerations limit the size of each heliostat to about 100 m^2. These plants typically achieve concentrations ratios between 300 and 1500 with operating temperatures between 500° C. and 1500° C. Another version of the central receiver concept is a system where a second large reflector is mounted at the top of the tower, redirecting the concentrated radiation from the heliostats downward to a ground level receiver. These Central Receiver systems can be designed to deliver electrical power outputs in the MWe range, but the cost is still high.

[0011] Parabolic trough systems are the most mature technology and plants with a total capacity of about 350 MWe have been constructed in the USA. The collectors consist of long parabolic trough reflectors and the receivers consist of tubes positioned on the line of focus of the parabolic collectors. The troughs rotate around the receiver tubes to track the movement of the sun. It is a linear concentration and the concentrations and temperatures obtained are lower than those of the two-dimensional technologies. The orientation of the troughs can either be North-South or East-West, each type having its own set of advantages and disadvantages. The concentration ratios are typically from 10 to 100 and the temperatures achieved range from 100° C. to 500° C. The Parabolic Trough technology requires many kilometers of fairly large steel support structures for the reflectors. Practical considerations usually limit the width of the reflectors to a few meters since the structures have to be designed to withstand adverse weather conditions.

[0012] The Linear Fresnel Reflector Concentrator systems employ a series of narrow mirrors mounted at ground level directing the solar radiation from two sides on a receiver tube mounted high above ground level. The mirrors are rotated to keep the focus on the receiver tube. The performance of these systems is similar to that of the Parabolic Trough systems but the utilization of the ground area is very good.

[0013] Due to the low power density of the solar radiation, collectors will have to cover an area of many square kilometers for a large plant. The cost of such large plants can be reduced if the technology used in the design, manufacture and/or operation of the collectors can be simplified. It is accordingly an object of the present invention to provide a trough thermal collector that can be very large, with a relatively simple tracking mechanism. The technology of the present invention can be scaled up to the GWe range and can deliver a significant contribution to the large-scale generation of electricity.

BRIEF DESCRIPTION OF THE INVENTION

[0014] According to a first aspect of the present invention there is provided apparatus for collection of solar energy, said apparatus comprising a part cylindrical trough, an elongate receiver extending in a generally axial direction relative to the cylindrical trough and at least one reflective surface disposed within the trough and configured to reflect incoming solar radiation towards the receiver.

[0015] The reflective surface may be part cylindrical in shape and may extend along the inside of the cylindrical trough. The apparatus may further include at least one corrector mirror disposed within the trough and support means configured to support the corrector mirror in a position where it can reflect radiation reflected from the cylindrical reflective surface of the trough, to the receiver.

[0016] The receiver may extend generally along the cylinder axis of the trough and the support means may be configured to rotate the corrector mirror relative to the cylinder axis.

[0017] The corrector mirror may be part cylindrical and may be disposed between the focal curve of the cylindrical trough and the reflective surface of the cylindrical trough.

[0018] The apparatus may include a system of corrector mirrors, supported by the support means.

[0019] The apparatus may include a parabolic mirror with the reflective surface being defined on the inside of the parabolic mirror. The apparatus may further include support means configured to support the parabolic mirror in a position where the principal axis of its parabolic shape generally intersects the receiver.

[0020] The support means may be configured to rotate the parabolic mirror relative to the cylinder axis.

[0021] The cylindrical trough may extend below the ambient ground surface, at least in part, but preferably entirely.

[0022] According to another aspect of the present invention there is provided a method for collection of solar energy, said method comprising receiving solar radiation in a part cylindrical trough, reflecting the radiation from a reflective surface to an axially orientated, elongate receiver and collecting the energy from the radiation at the receiver.

[0023] The reflective surface may be part cylindrical and may be defined on the inside of the cylindrical trough, in which case the method may comprise receiving the solar radiation on the cylindrical reflective surface, reflecting the radiation from the cylindrical reflective surface and correcting the radiation reflected from the cylindrical reflective surface by reflecting it to the receiver.

[0024] The radiation reflected from the cylindrical reflective surface may be corrected by reflecting it from at least one corrector mirror or by reflecting it from a system of corrector mirrors, towards the receiver.

[0025] The receiver may extend generally along the cylinder axis of the cylindrical surface and the method may include rotating each corrector mirror relative to the cylinder axis to track angular changes in the incoming solar radiation.

[0026] The reflective surface may be defined on the inside of a parabolic mirror that is supported within the cylindrical trough, the principal axis of the parabolic shape of the reflective surface generally intersecting the receiver, in which case the method may comprise receiving the radiation on the parabolic reflective surface and reflecting it from the reflective surface to the receiver.

[0027] The receiver may extend generally along the cylinder axis, said method including rotating the reflective surface relative to the cylinder axis to track angular changes in the incoming solar radiation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of non-limiting example, to the accompanying drawings in which:

[0029] FIG. **1** is a schematic end view of a solar energy collector in accordance with the present invention, showing some basic concepts;

[0030] FIG. **2** is a schematic end view of a solar energy collector in accordance with a first embodiment of the invention shown in there positions, at different times of the day;

[0031] FIG. **3** is a schematic end view of a solar energy collector in accordance with a second embodiment of the invention shown in there positions, at different times of the day;

[0032] FIG. **4** is a detail schematic end view of the collector of FIG. **3**;

[0033] FIG. **5** shows a table of coordinates of endpoints of mirrors in the collector of FIGS. **3** and **4**;

[0034] FIG. **6** shows a table of radii and centre coordinates of the corrector mirrors of the collector of FIGS. **3** and **4**;

[0035] FIG. **7** shows a detail end view of a corrector mirror and receiver tube of the collector of FIGS. **3** and **4**; and

[0036] FIG. **8** shows a spread of the intensity of reflected radiation at the respective points of focus for different components of the collector.

DETAILED DESCRIPTION OF THE DRAWINGS

[0037] In the drawings, a solar energy collector in accordance with the present invention is indicated generally by reference numeral **10**.

[0038] Referring to FIG. **1**, the collection of solar radiation **12** in the collector **10** is done in a series of elongate parallel half-cylindrical troughs **14** below ground level. These troughs **14** are accurately aligned with a North-South orientation, although an East-West orientation could be used. FIG. **1** is an end view looking in a northerly direction. Reflective surfaces within the troughs **14** concentrate the incident solar radiation **12** on a fixed receiver tube **16** situated at the center of curvature of the trough **14**. The collector has a tracking mechanism (not shown in FIG. **1**) that tracks movement of the radiation **12** to ensure that it is reflected towards the receiver tube **16** and this tracking mechanism has a cylindrical symmetry around the point of focus at the cylinder axis, i.e. at the receiver tube. The diameter of each trough **14** can be quite large and its size is only limited by civil or mechanical engineering constraints. For the purpose of quantitative analyses a trough with diameter of 20 m or R=10 m will be considered herein below (where R is the radius of the circular trough **14**).

[0039] The lengths of the troughs **14** are determined by engineering constraints of the internal support structures and pipe work. Provision is made along the lengths for the effects of the latitude of the site and seasonal variation of the sun's angle. Since these considerations are the same as those of present parabolic trough systems no further attention will be given to aspects concerning the lengths of the troughs **14**. The troughs **14** preferably have some slope along their lengths to allow for water drainage in the case of rain. Since the optics must remain stable the troughs **14** are preferably constructed at sites where the ground is geologically quite stable.

[0040] The thermal energy of the radiation **12** is collected in the receiver tubes **16** and the same technology applies here concerning selective absorbers and thermal insulation as in present parabolic trough systems. The technologies of the thermal energy transport, energy storage and conversion to electricity through some thermodynamic cycle are also similar and these aspects will not be considered further.

[0041] The motivation for the invention shown in FIG. **1** is that the present above-ground steel support structures are replaced with solid troughs **14** below the ground level. The requirements to design structures that can withstand adverse wind conditions are thus significantly reduced. There is also less visual impact on the environment since the structures in the trough **14** are below the ambient ground level.

[0042] Referring to FIG. **2**, an optical collector **10.1** in accordance with a first embodiment of the invention is shown and includes a large parabolic mirror **18** with focal length about 9.33 m. Since the collector mirror **18** must move in the cylindrical trough **14** to track the sun's movement, the width of the mirror will have to be smaller than the diameter of the trough. The aperture width of the mirror **18** is chosen to be half the diameter of the trough **14** or equal to the radius of curvature. In this case the width of the mirror **18** is R=10 m. With this width the mirror **18** can rotate through an angle of 60° to either side of the vertical. For larger angles some radiation will be cut off by the opposite wall of the trough **14** and the mirror **18** will move out of the trough.

[0043] In FIG. **2**, the collector **10.1** is shown from a northerly direction, similar to FIG. **1** and examples of positions of the mirror **18** in the morning, at noon and in the afternoon are illustrated, respectively, to illustrate the movement of the mirror during the course of a day. A disadvantage of this embodiment of the invention is that area exposed to radiation **12** that is utilized by the collector **10.1** is limited to a maximum of 50% of the ground area occupied by the collector. This disadvantage is however compensated for by the advantages of the simple technology involved. An inherent limitation of the system is that the sun can only be tracked through an angle of 120°. This is not very serious since the intensity of the sun's radiation **12** drops significantly for large azimuth angles.

[0044] Although the collector **10.1** shown in FIG. **2** works fine, it employs a very large mirror **18**. The mirror **18** can obviously be constructed in several smaller sections but a large support structure will still be required to move the mirror with the degree of accuracy required to obtain a sharp focus on the receiver tube **16**. The effect of wind turbulence in the troughs **14** will also be severe on a mirror **18** with such a large area.

[0045] Referring to FIGS. **3** and **4**, a collector **10.2** in accordance with a second embodiment of the invention is shown as viewed in a northerly direction, in which the incident radiation **12** is concentrated on the receiver tube **16** in a different way. The inner surface of the cylindrical trough **14** is reflective and itself acts as the primary collecting mirror **20** while the tracking of the sun is achieved by the rotation of a smaller assembly or "box"**22** containing corrector mirrors. The corrector mirrors focus the rays reflected by the cylindrical mirror **20**, at the center of curvature R_o of the trough **14**, i.e. at the receiver tube **16**. The large primary collecting mirror **20** thus remains stationary, while only the much smaller corrector box **22** is moved. In FIG. **3**, examples of positions of the corrector box **22** in the morning, at noon and in the afternoon are illustrated, respectively, to illustrate the movement of the corrector box during the course of a day. A disadvantage of this collector **10.2** is that only 50% of area of the mirror **20** is utilized.

[0046] The wall **24** of the trough **14** is made of concrete that is accurately profiled or steel sections with the required diameter and profile. The primary mirror **20** on the inner surface of the wall **24** comprises reflectors that consist of thin polymer sheets with reflecting surfaces attached to the wall **24**. The reflectivity of the primary mirror **20** must be high to minimize losses due to the multiple reflections in the corrector box **22**. The main advantage of this collector **10.2** is that the primary mirror **20** is permanently fixed and does not require above-ground or moving support structures and can thus be very large.

[**0047**] A parabolic mirror has a single focal point for all incident rays parallel to the principle axis (paraxial rays). For this reason parabolic mirrors are employed in concentrator systems. In the case for a spherical or cylindrical profile such as that of the primary mirror **20**, only parallel incident rays close to a principle axis (any line perpendicular to the surface) are concentrated at a single focal point at f=½R, where R is the radius of the cylinder. For parallel rays further away from the principle axis **34** spherical aberration occurs and a focal curve is defined (shown as F in FIG. **4**). Due to the geometric limitations in the troughs **14**, only rays up to ½R from the principle axis **34** are utilized and the aberration of these rays can be corrected. The corrector box **22** shown in FIG. **3** (and shown as an insert in FIG. **4**) contains corrector mirrors **28** that perform two optical corrections: (a) The primary focal point is shifted from ½R to R (i.e. is shifted from F to the centre of curvature designated R_o, which is also where the receiver tube **16** is situated) and (b) the effects of spherical aberration are corrected so that all rays converge at a single focal point at R_o.

[**0048**] A further advantage of the collector **10.2** is that the corrector box **22** is a relatively small structure that contains corrector mirrors **28** of small widths, that has to be rotated instead of rotating a large mirror. This movement of the corrector box **22** can be on rails mounted on the walls **24**, it can swing around a support at the center of curvature, or the like. Another rotating, small corrector mirror **30** above the receiver tube **16** is preferably employed in some cases.

[**0049**] Although it is proposed that the trough **14** be mounted in the ground, the large primary mirror **20** can be mounted above ground if it will be less expensive to construct or will have other advantages. The advantages of having a fixed large primary mirror **20** will still apply.

[**0050**] The collector system **10.2** can also be used for concentrator PV systems where the PV cells are mounted in a triangular shape around the receiver tube **16**. Combined electrical and heat generation can be achieved in this case. The collector system **10.2** can also be employed for steam generation or water heating.

[**0051**] It is theoretically possible to obtain a perfect line focus at R_o of all paraxial rays by employing a set of mirrors with special profiles in the corrector box **22**. Since the receiver tube **16** has a finite width, the requirement of a line focus changes to that of a focus with a smaller width than the width of the receiver tube. Due to the finite size of the sun it can not be considered as a point source of the radiation **12** and the rays are not all paraxial, but are incident on the primary mirror **20** with angles that vary from −0.266° to +0.266° from the perpendicular ray. This leads to a theoretical limit for the concentration ratio of about 108 for the aperture angle of 60°.

[**0052**] There is an infinite number of ways to arrange a set of the corrector mirrors **28** to perform the required optical correction. In the embodiment illustrated, the emphasis is on simplicity and cost reduction without sacrificing too much optical concentration. The following criteria have been taken into account: (a) The corrector system **26** (of corrector mirrors **28**) must yield a good focus on the receiver tube **16** at R_o; (b) the profiles of the corrector mirrors **28** must preferably be either flat or cylindrical, to keep its cost low; (c) the size of the corrector box **22** must be as small as possible; and (d) the maximum amount of the incident beam of 10 m wide must be utilized.

[**0053**] In all configurations of the corrector system **26**, the corrector mirrors **28** will redirect the reflected rays so that they have to pass through a center gap **32** to the receiver tube **16**. This inevitably leads to a loss since the incident radiation in this gap **32** cannot be utilized. This is not quite so serious since it allows the use of the additional small corrector mirror **30** in the path of rays directed to this gap **32**, to improve the concentration. There are always losses due to some absorption of the reflective surfaces and the multiple reflections involved in the corrector system **26** make the system inherently less efficient than the case where only one reflection is involved, as in the collector **10.1** shown in FIG. **2**. All configurations of the corrector system **26** employ an identical ("mirrored" about the principle axis **34**) set of corrector mirrors **28** on either side of the principle axis **34**, but only rays **12** on one side of the axis are shown in FIG. **4** and will be described here. In the vicinity of the focal curve F, rays reflected from the primary mirror **20** are converging and corrector mirrors **28** should be placed either below or above the focal curve. For the latter case the corrector mirrors **28** have to be quite large and this case will not be considered. Only one preferred embodiment of the corrector system **26** is described in detail, but many variations on the basic arrangement are possible.

[**0054**] The choice of the design or configuration of the corrector mirrors **28** in the corrector system **26** is determined by engineering considerations concerning the manufacturing of the corrector mirrors and support structures, as well as cost aspects. The preferred embodiment described here was obtained by computer simulation.

[**0055**] FIG. **4** shows a corrector system **26** where all the corrector mirrors **28** have cylindrical profiles. The coordinates of the endpoints of the corrector mirrors as shown in FIG. **4** are provided in the Table of FIG. **5**. The individual corrector mirrors **28** in the corrector box **22** are designated in FIG. **4** as **28.1**, **28.2** and **28.3**, while the corrector mirror above the receiver tube **16** is designated as **30**.

[**0056**] The size of the corrector box **22** containing the corrector mirrors **28** is indicated (to scale) by the insert at the top right in FIG. **4**. The dimensions of the rectangular corrector box **22** are 4×0.7 m. The corrector mirrors **28**, **30** can be supported with steel frames or beams (indicated by the crossed circles **36**) that run along the length of the corrector box **22** and above the corrector mirror **30**. The total width of all the corrector mirrors **28** in the corrector box **22** is 7.54 m and the width of the center gap **32** is 1.0 m. The coordinates of the corrector mirrors **28**, **30** are given in the table of FIG. **6**, where R is the radius of curvature and [XO:YO] are the coordinates of the centers of curvature for each correcting mirror in the axis system of FIG. **4**.

[**0057**] FIG. **4** shows the reflections for paraxial incident rays **12**. The reflections of mirrors **20**, **28.1** and **28.2** yield a focus of width about 35 mm at the center of curvature R_o for this embodiment. The effect of the conical character of the rays **12** from the sun causes slight shifts of all rays at corrector mirrors **28**.**1** and **28**.**2** and the focused rays are spread out over a width of about 80 mm at R_o. These rays can be focused on the receiver tube **16** by corrector mirror **30** mounted above it. FIG. **7** shows these reflections in greater detail. It is assumed that the receiver tube **16** has a diameter of 80 mm. Beam A represents the outer rays of the reflected beam for the rays of the sun incident at 89.734°. B and C similarly represent the beams of rays incident at 90° and 90.266° respectively. The optical paths of all other rays are between the extremes depicted in FIG. **7**.

[**0058**] Corrector mirror **28**.**3** (FIG. **4**) reflects the rays shaded by mirror **28**.**1**. All these rays reflected by corrector mirror **28**.**3** are focused on the lower half of the receiver tube **16** and corrector mirror **30** is not involved. The corrector box **22** and corrector mirror **30** are now rotated around the center of curvature R_o to track the sun.

[**0059**] The spread of the intensity (in arbitrary units) at the point of focus for the different components is shown in FIG. **8**. Curve A represents the spread on a horizontal plane of a parabolic mirror as shown in FIG. **2**. (A gap of 1 m at the center is allowed for quantitative comparison with the other curves.) The spread due to the conical character of the sun's rays is about 10 cm for a parabolic concentrator. Curve B represents the intensity of mirror **28**.**3** as spread over the diameter of the absorber tube **16** of diameter 8 cm. Curve C represents the spread from mirrors **28**.**1**, **28**.**2** and **30** over the absorber tube **16**, while curve D represents the combined effect of all the reflections from correcting mirrors **28**.**1**, **28**.**2**, **28**.**3** and **30**.

[**0060**] The effect of reflection losses is not taken into account in FIG. **8**. A parabolic concentrator has only one reflection. In the case of curve D (i.e. the collector system **10**.**2** of FIGS. **3** and **4**) 30% of the rays has one reflection; 13% has three reflections; 47% has four reflections while 10% of the incident beam is lost. The reflection losses will lower the relative intensities of curves C and D in FIG. **8**.

[**0061**] In the collector system **10**.**2** shown in FIGS. **3** and **4**, all the rays **12** from the aperture of 9 m are concentrated over a width of 8 cm corresponding to a concentration of about 110. This concentration compares favorably with that of a single parabolic concentrator.

[**0062**] The invention illustrated holds the advantages that larger mirrors **18**, can be used than in known above-ground solar collectors, since the size of the mirrors is not limited by engineering constraints of the structures that would otherwise have to support them above ground. In the second illustrated embodiment of the invention, instead of rotating a large primary mirror as in known solar collectors, only the relatively small corrector box **22** needs to be rotated to track movement of the sun. The invention's ability to allow use of large primary mirrors **20** and rotation of the relatively small corrector box **22** allows the collector **10** to be scaled up so that solar-electric power plants in the GWe range become feasible with this large collector system. The invention can also be applied as a as concentrator for PV cells or for heating water in households.

1. Apparatus for collection of solar energy, said apparatus comprising a part cylindrical trough, an elongate receiver extending in a generally axial direction relative to the cylindrical trough and at least one reflective surface disposed within the trough and configured to reflect incoming solar radiation towards the receiver.

2. Apparatus as claimed in claim 1, wherein said reflective surface is part cylindrical in shape and extends along the inside of the cylindrical trough, said apparatus further including at least one corrector mirror disposed within the trough and support means configured to support the corrector mirror in a position where it can reflect radiation reflected from the cylindrical reflective surface of the trough, to the receiver.

3. Apparatus as claimed in claim 2, wherein the receiver extends generally along the cylinder axis of the trough.

4. Apparatus as claimed in claim 3, wherein the support means is configured to rotate the corrector mirror relative to the cylinder axis.

5. Apparatus as claimed in claim 2, wherein the corrector mirror is part cylindrical.

6. Apparatus as claimed in claim 2, wherein the corrector mirror is disposed between the focal curve of the cylindrical trough and the reflective surface of the cylindrical trough.

7. Apparatus as claimed in claim 2, which includes a system of corrector mirrors, supported by the support means.

8. Apparatus as claimed in claim 1, which includes a parabolic mirror, said reflective surface being defined on the inside of the parabolic mirror, said apparatus further including support means configured to support the parabolic mirror in a position where the principal axis of its parabolic shape generally intersects the receiver.

9. Apparatus as claimed in claim 8, wherein the receiver extends generally along the cylinder axis of the trough.

10. Apparatus as claimed in claim 9, wherein the support means is configured to rotate the parabolic mirror relative to the cylinder axis.

11. Apparatus as claimed in claim 1, in which the cylindrical trough extends below the ambient ground surface, at least in part.

12. A method for collection of solar energy, said method comprising receiving solar radiation in a part cylindrical trough, reflecting the radiation from a reflective surface to an axially orientated, elongate receiver and collecting the energy from the radiation at the receiver.

13. A method as claimed in claim 12, wherein the reflective surface is part cylindrical and is defined on the inside of the cylindrical trough, said method further comprising receiving the solar radiation on the cylindrical reflective surface, reflecting the radiation from the cylindrical reflective surface and correcting the radiation reflected from the cylindrical reflective surface by reflecting it to the receiver.

14. A method as claimed in claim 13, wherein the radiation reflected from the cylindrical reflective surface is corrected by reflecting it from at least one corrector mirror.

15. A method as claimed in claim 14, wherein the radiation reflected from the cylindrical reflective surface is corrected by reflecting it from a system of corrector mirrors, towards the receiver.

16. A method as claimed in claim 14, wherein the receiver extends generally along the cylinder axis of the cylindrical surface, said method including rotating each corrector mirror relative to the cylinder axis to track angular changes in the incoming solar radiation.

17. A method as claimed in claim 12, wherein the reflective surface is defined on the inside of a parabolic mirror that is supported within the cylindrical trough, the principal axis of the parabolic shape of the reflective surface generally intersecting the receiver, said method further comprising receiving the radiation on the parabolic reflective surface and reflecting it from the reflective surface to the receiver.

18. A method as claimed in claim 17, wherein the receiver extends generally along the cylinder axis, said method including rotating the reflective surface relative to the cylinder axis to track angular changes in the incoming solar radiation.

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