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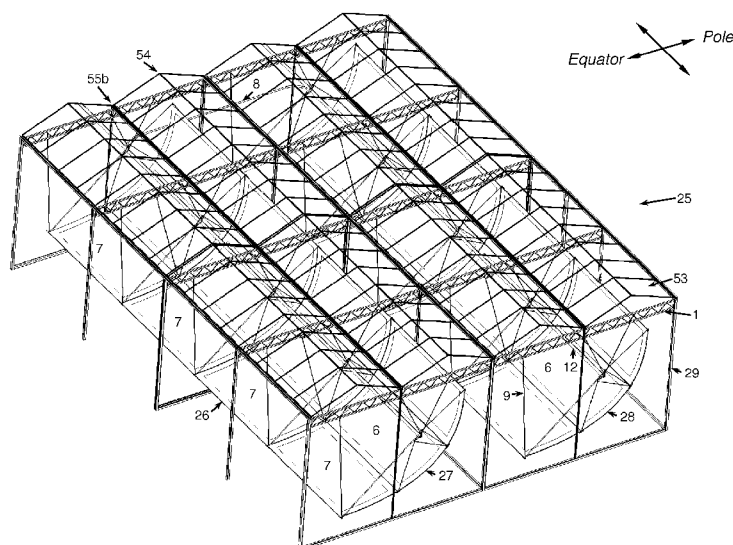


Fig. 1

(57) Abstract: A protective transparent enclosure (such as a glasshouse or a greenhouse) encloses a concentrated solar power system. The concentrated solar power system includes one or more solar concentrators and one or more solar receivers. Thermal power is provided to an industrial process, electrical power is provided to an electrical distribution grid, or both. In some embodiments, the solar concentrators are parabolic trough concentrators with one or more lateral extensions. In some embodiments, the lateral extension is a unilateral extension of the primary parabolic trough shape. In some embodiments, the lateral extensions are movably connected to the primary portion. In some embodiments, the lateral extensions have a focal line separate from the focal line of the base portion. In some embodiments, the greenhouse is a Dutch Venlo style greenhouse.

CONCENTRATING SOLAR POWER WITH GLASSHOUSES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] Priority benefit claims for this application are made in the accompanying Application Data Sheet, Request, or Transmittal (as appropriate, if any). To the extent permitted by the type of the instant application, this application incorporates by reference for all purposes the following applications, all commonly owned with the instant application at the time the invention was made:

U.S. Provisional Application (Docket No. 310618-2001 and Serial No. 61/149,292), filed 02/02/2009, first named inventor Rod MacGregor, and entitled

Concentrating Solar Power with Glasshouses;

U.S. Provisional Application (Docket No. CLEN-002/00US 310618-2002 and Serial No. 61/176,041), filed 05/06/2009, first named inventor Peter Von Behrens, and entitled **Concentrating PhotoVoltaics with Glasshouses;**

PCT Application (Docket No. GP-09-01PCT and Serial No. PCT/US 10/22780), filed 02/01/2010, first named inventor Roderick MacGregor, and entitled

Concentrating Solar Power with Glasshouses; and

U.S. Provisional Application (Docket No. GP-10-02 and Serial No. 61/361,509), filed 07/05/2010, first named inventor Peter Von Behrens, and entitled

Concentrating Solar Power with Glasshouses.

BACKGROUND

[0002] Field: Advancements in concentrated solar thermal power (CST), photovoltaic solar energy (PV), concentrated photovoltaic solar energy (CPV), and industrial use of concentrated solar thermal energy are needed to provide improvements in performance, efficiency, and utility of use.

[0003] Related Art: Unless expressly identified as being publicly or well known, mention herein of techniques and concepts, including for context, definitions, or comparison purposes, should not be construed as an admission that such techniques and concepts are previously publicly known or otherwise part of the prior art. All references cited herein (if any),

1 including patents, patent applications, and publications, are hereby incorporated by reference in
2 their entireties, whether specifically incorporated or not, for all purposes.

3
4 **[0004]** Concentrated solar power systems use mirrors, known as concentrators, to
5 gather solar energy over a large space and aim and focus the energy at receivers that convert
6 incoming solar energy to another form, such as heat or electricity. There are several advantages,
7 in some usage scenarios, to concentrated systems over simpler systems that directly use incident
8 solar energy. One advantage is that more concentrated solar energy is more efficiently
9 transformed to heat or electricity than less concentrated solar energy. Thermal and photovoltaic
10 solar receivers operate more efficiently at higher incident solar energy levels. Another
11 advantage is that non-concentrated solar energy receivers are, in some usage scenarios, more
12 expensive than mirror systems used to concentrate sunlight. Thus, by building a system with
13 mirrors, total cost of gathering sunlight over a given area and converting the gathered sunlight to
14 useful energy is reduced.

15
16 **[0005]** Concentrated solar energy collection systems, in some contexts, are divided into
17 four types based on whether the solar energy is concentrated into a line-focus receiver or a point-
18 focus receiver and whether the concentrators are single monolithic reflectors or multiple
19 reflectors arranged as a Fresnel reflector to approximate a monolithic reflector.

20
21 **[0006]** A line-focus receiver is a receiver with a target that is a relatively long straight
22 line, like a pipe. A line-focus concentrator is a reflector (made up of a single smooth reflective
23 surface, multiple fixed facets, or multiple movable Fresnel facets) that receives sunlight over a
24 two dimensional space and concentrates the sunlight into a significantly smaller focal point in
25 one dimension (width) while reflecting the sunlight without concentration in the other dimension
26 (length) thus creating a focal line. A line-focus concentrator with a line-focus receiver at its
27 focal line is a basic trough system. The concentrator is optionally rotated in one dimension
28 around its focal line to track daily or seasonal (apparent) movement of the sun to improve total
29 energy capture and conversion.

30
31 **[0007]** A point-focus receiver is a receiver target that is essentially a point, but in
32 various approaches is a panel, window, spot, ball, or other target shape, generally more equal in
33 width and length than a line-focus receiver. A point-focus concentrator is a reflector (made up
34 of a single smooth reflective surface, multiple fixed facets, or multiple movable Fresnel facets)
35 that receives sunlight over a two-dimensional space and concentrates the sunlight into a
36 significantly smaller focal point in two dimensions (width and length). A monolithic point-focus

1 concentrator with a point-focus receiver at its focal point is a basic dish concentrated solar
2 system. The monolithic concentrator is optionally rotated in two dimensions to rotate its focal
3 axis around its focal point to track daily and seasonal movement of the sun to improve total
4 energy capture and conversion.

5
6 **[0008]** A parabolic trough system is a line concentrating system using a monolithic
7 reflector shaped like a large half pipe having a shape defined by the equation $y^2=4fx$ where f is
8 the focal length of the trough. The reflector has a 1-dimensional curvature to focus sunlight onto
9 a line-focus receiver or approximates such curvature through multiple facets fixed relative to
10 each other.

11
12 **[0009]** A concentrating Fresnel reflector is a line concentrating system similar to the
13 parabolic trough replacing the trough with a series of mirrors, each the length of a receiver, that
14 are flat or alternatively slightly curved in width. Each mirror is individually rotated about its
15 long axis to aim incident sunlight onto the line-focus receiver.

16
17 **[0010]** A parabolic dish system is a point concentrating system using a monolithic
18 reflector shaped like a bowl. The reflector has a 2-dimensional curvature to focus sunlight onto
19 a point-focus receiver or approximates such curvature through multiple flat or alternatively
20 curved facets fixed relative to each other.

21
22 **[0011]** A solar power tower is a point concentrating system similar to the parabolic
23 dish, replacing the dish with a 2-dimensional array of mirrors that are flat or alternatively
24 curved. Each mirror (heliostat) is individually rotated in two dimensions to aim incident
25 sunlight onto a point-focus receiver. The individual mirrors and an associated control system are
26 parts of a point-focus concentrator with a focal axis that rotates around its focal point.

27
28 **[0012]** In solar thermal systems, the receiver is a light to heat transducer. The receiver
29 absorbs solar energy, transforming it to heat and transmitting the heat to a thermal transport
30 medium such as water, steam, oil, or molten salt. The receiver converts solar energy to heat and
31 minimizes and/or reduces heat loss due to thermal radiation. In concentrated photovoltaic
32 systems, the receiver is a photovoltaic surface that directly generates electricity from sunlight.
33 In some solar thermal systems, CPV and CST are combined in a single system where a thermal
34 energy system generates thermal energy and acts as a heat sink for photovoltaic cells that operate
35 more efficiently when cooled. Other receivers, such as a Stirling engine, that use solar energy to

1 generate heat and then locally convert the heat to electricity through mechanical motion and an
2 electric generator, are also deployed as a receiver, in some approaches.

3
4 **[0013]** In some concentrated solar systems, such as some systems with high
5 concentration ratios, overall system is cost dominated by various elements such as the
6 concentration system (such as a mirror or lens), a support system for the concentrators, and
7 motors and mechanisms that enable tracking movement of the sun. The elements dominate the
8 costs because the elements are enabled to withstand wind and weather. In some usage scenarios,
9 solar energy systems are enabled to withstand various environmental dangers such as wind, rain,
10 snow, ice, hail, dew, rodents, birds and other animals, dust, sand, moss, and other living
11 organisms. Reflectivity of a concentrator is sensitive to damage, tarnishing, and dirt buildup
12 since only directly reflected sunlight, not scattered sunlight, is effectively focused.

13
14 **[0014]** Glass mirrors are used in some concentrated systems, because of an ability to
15 maintain good optical properties over long design lives (e.g. 30 years) of concentrated solar
16 systems. Glass is relatively fragile and vulnerable to hail and other forms of damage unless it is
17 suitably thick, e.g. 4-5 mm for relatively larger mirrors. In a 400 square foot concentrating dish
18 the thickness results in a weight of close to 1000 lbs or about nine kg per square meter of
19 concentrator area. The mirror is formed in a precise curve, in one dimension for a trough, in two
20 dimensions for a dish, to focus sunlight.

21
22 **[0015]** In some concentrated systems, mirror surfaces cease to focus as intended if
23 warped. Thus, the reflector is supported and held in shape by a metal superstructure that is
24 shaped to the curved glass. The superstructure supports and protects the mirror from
25 environmental conditions such as winds of 75mph or more. The protection from winds adds an
26 additional 10,000 lbs of load beyond the 1000 lb weight of the mirror, resulting in complex
27 construction requiring roughly 20 kg of structural steel for every square meter of mirror area in a
28 dish system.

29
30 **[0016]** In some concentrated systems, concentrator tracking motors move the 30 kg per
31 square meter weight of the concentrator, and also overcome force of wind that exceeds an
32 additional 300 kg per square meter. The motors are exposed to environmental elements (such as,
33 dirt, dust, moisture, etc).

34
35 **[0017]** In some concentrated systems, troughs are spaced relatively far apart on (e.g.
36 level) ground to avoid shading each other. Avoiding shading is important because the trough

1 mirror is relatively expensive and so having any mirror shaded (and unproductive) is costly.
2 Few approaches exceed ground coverage of 33% since that spacing avoids shading in winter (for
3 an east/west orientation) or early/late in the day (for a north/south orientation). Some east/west
4 orientations (e.g. with 33% ground coverage), have essentially no shading of any trough surface
5 by another at any time during the day or year, capture almost all incident light within a trough
6 array boundary during the winter (when the troughs are held vertical), but capture only about 1/3
7 of incident light within the the trough array boundary during the summer (when the troughs are
8 held horizontal).

9
10 **[0018]** Troughs are placeable with length running north/south or east/west. If placed
11 running north/south, then they are rotated during the day to track the daily movement of the sun
12 and keep incident light focused on the receiver. In the morning, the trough is aimed to the east at
13 the rising sun, at noon it is aimed up at the noonday sun, and in the evening it is aimed to the
14 west at the setting sun. North/south troughs do not track seasonal variation in sun position.
15 Instead, as the sun moves lower in the sky (toward the horizon of the equator) during the winter,
16 light strikes the trough and reflects up the trough (away from the equator) to the receiver. In
17 some instances, if troughs are oriented east/west, then they are rotated as the seasons progress to
18 aim at the sun. During the summer the trough is held somewhat horizontal, aimed more or less
19 straight up at the summer sun. During the winter the trough is held somewhat vertical, aimed
20 toward the sun that is lower in the sky in the direction of the equator. In some instances, an
21 east/west trough does not track the daily motion of the sun. Instead, when light comes from the
22 east in the morning, it reflects off the trough and travels further west until it hits the receiver.
23 Similarly, in the evening, the light hits the trough and travels further east down the trough until it
24 hits the receiver.

25 26 27 SYNOPSIS

28
29 **[0019]** The invention may be implemented in numerous ways, including as a process,
30 an article of manufacture, an apparatus, a system, and a composition of matter. In this
31 specification, these implementations, or any other form that the invention may take, may be
32 referred to as techniques. The Detailed Description provides an exposition of one or more
33 embodiments of the invention that enable improvements in performance, efficiency, and utility
34 of use in the field identified above. The Detailed Description includes an Introduction to
35 facilitate the more rapid understanding of the remainder of the Detailed Description. As is

discussed in more detail in the Conclusions, the invention encompasses all possible modifications and variations within the scope of the issued claims.

Brief Description of Drawings

[0020] Fig. 1 illustrates a perspective view of selected details of a portion of an embodiment of an enclosing greenhouse and an enclosed concentrated solar energy system utilizing a parabolic trough with a unilateral extension.

[0021] Fig. 2a illustrates a cross-section view of a bilaterally symmetric trough with a symmetric portion and a unilateral extension collectively having one continuous shape.

[0022] Fig. 2b illustrates a cross-section view of a bilaterally symmetric trough with various styles of unilateral extensions.

[0023] Fig. 3a illustrates a cross-section view of paths of selected incident light hitting a bilaterally symmetric trough with a unilateral extension and reflecting onto a secondary reflector and a solar receiver.

[0024] Fig. 3b illustrates a cross-section view of a solar receiver, a solar receiver insulator, and an integrated secondary reflector, and also illustrates paths of selected light rays.

[0025] Figs. 4a and 4b respectively illustrate selected details of an embodiment of a greenhouse enclosure with enclosed solar concentrators utilizing a fixed unilateral extension and solar receivers in respective incident sunlight contexts: high angle (summer) and low angle (winter).

[0026] Figs. 5a and 5b respectively illustrate selected details of an embodiment of a greenhouse enclosure with enclosed solar concentrators utilizing a movable unilateral extension and solar receivers in respective incident sunlight contexts: high angle (summer) and low angle (winter).

[0027] Figs. 6a and 6b illustrate perspective views of selected details of an embodiment of suspension mechanisms enabled to suspend solar receivers from greenhouse superstructure

1 and suspend solar concentrators with respective focal points fixed on the respective solar
2 receivers.

3
4 **[0028]** Fig. 7 illustrates a perspective view of selected details of an embodiment of a
5 parabolic trough solar concentrator with a unilateral extension, a solar receiver, and a suspension
6 mechanism that enable the solar concentrator to rotate about the solar receiver.

7
8 **[0029]** Figs. 8a and 8b illustrate views of selected details of an embodiment of a solar
9 receiver, solar receiver insulation, and an integrated secondary reflector, and further illustrate
10 some paths of incident light to the secondary reflector and the solar receiver.

11
12 **[0030]** Figs. 9a and 9b illustrate respective shapes and focal points of troughs of equal
13 aperture, illustrating respectively a bilaterally symmetric trough and a trough with a shortened
14 focal length and a unilateral extension.

15
16 **[0031]** Figs. 10a and 10b respectively illustrate percent of energy received at a solar
17 receiver under equal conditions for each point in an aperture of a solar concentrator, respectively
18 for a bilaterally symmetric trough and a trough with a shortened focal length and a unilateral
19 extension.

20
21 **[0032]** Figs. 11a and 11b respectively illustrate efficiency as measured by position of a
22 shade line in an aperture and by percent of shading respectively for a bilaterally symmetric
23 trough and a trough with a shortened focal length and a unilateral extension.

DETAILED DESCRIPTION

[0033] A detailed description of one or more embodiments of the invention is provided below along with accompanying figures illustrating selected details of the invention. The invention is described in connection with the embodiments. The embodiments herein are understood to be merely exemplary, the invention is expressly not limited to or by any or all of the embodiments herein, and the invention encompasses numerous alternatives, modifications, and equivalents. To avoid monotony in the exposition, a variety of word labels (including but not limited to: first, last, certain, various, further, other, particular, select, some, and notable) may be applied to separate sets of embodiments; as used herein such labels are expressly not meant to convey quality, or any form of preference or prejudice, but merely to conveniently distinguish among the separate sets. The order of some operations of disclosed processes is alterable within the scope of the invention. Wherever multiple embodiments serve to describe variations in process, method, and/or features, other embodiments are contemplated that in accordance with a predetermined or a dynamically determined criterion perform static and/or dynamic selection of one of a plurality of modes of operation corresponding respectively to a plurality of the multiple embodiments. Numerous specific details are set forth in the following description to provide a thorough understanding of the invention. The details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of the details. For the purpose of clarity, technical material that is known in the technical fields related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

INTRODUCTION

[0034] This introduction is included only to facilitate the more rapid understanding of the Detailed Description; the invention is not limited to the concepts presented in the introduction (including explicit examples, if any), as the paragraphs of any introduction are necessarily an abridged view of the entire subject and are not meant to be an exhaustive or restrictive description. For example, the introduction that follows provides overview information limited by space and organization to only certain embodiments. There are many other embodiments, including those to which claims will ultimately be drawn, discussed throughout the balance of the specification.

1 **[0035]** In some circumstances, techniques described herein enable cost reduction of
2 concentrated solar power systems. In various embodiments, collection (concentration and
3 conversion of solar energy) is separated from protection. A protective transparent exoskeleton
4 (such as a glasshouse or a greenhouse) surrounds and/or encloses collecting elements (or
5 alternatively the collecting elements are placed in the exoskeleton), enabling the collecting
6 elements (mirrors, lenses, etc) to be less robust than otherwise required. By separating
7 collecting and protecting functions, and leveraging off-the-shelf technology (e.g. highly
8 engineered, cost effective, and proven greenhouse technology, such as glass growers greenhouse
9 technology) for the protection function, in some circumstances a reduction in cost and
10 complexity of a system (such as mirrors/lenses, support structure, foundations, tracking
11 mechanisms, etc.) is enabled with a relatively minimal impact on overall performance. The
12 glasshouse is relatively low to the ground with little wind force bearing surfaces, and is designed
13 to withstand wind and weather with a relatively minimal structural skeleton. Because the
14 glasshouse reduces wind forces acting on the collector and receiver elements, the mirrors or
15 lenses used for collection and concentration inside the exoskeletal protection of the glasshouse
16 are enabled to be lightweight, in some embodiments, to a point of seeming flimsy, and thus are
17 relatively less costly to construct, transport, support and aim, and have little or no weatherization
18 costs. Note that within this disclosure, the terms glasshouse and greenhouse are used
19 interchangeably, and are not meant to necessarily imply any sort of horticultural activity.

21 **[0036]** The protected embodiment techniques enable reflectors built from lighter
22 materials with simpler and lighter frames since wind, weather, and UV light are reduced inside a
23 glasshouse enclosure. Foundation, suspension, and tracking mechanisms for receivers and
24 concentrators are enabled to be simpler, lighter, and less expensive.

26 **[0037]** Some embodiments of a concentrated solar system inside a glasshouse have an
27 array of relatively large 2-D-freedomed, 1-D-solar-tracking parabolic troughs suspended from
28 fixed roof locations.

30 **[0038]** A glasshouse, such as a commercial greenhouse, efficiently supports flat glass
31 planes. Supporting framework of straight metal sections brace each other and attach to the
32 ground in multiple places. Some glasshouses designed to withstand the same weather conditions
33 as an external parabolic dish require less than half as much structural steel (less than 10 kg) per
34 square meter of concentrator, compared to an external parabolic dish. Total weight, including 4-
35 5mm glass, is less than 20 kg per square meter of concentrator, for the glasshouse.

1 **[0039]** According to various embodiments, concentrators are made entirely or partially
2 of thin-gauge aluminum foil, reflective film, or other relatively reflective and lightweight
3 materials. Some of the materials have higher reflectivity than glass mirrors. Concentrators, in
4 some embodiments, are foam core combined with reflective material, enabling concentrators
5 weighing less than one kg per square meter. Lightweight construction, in some usage scenarios,
6 reduces one or more of costs associated with production, transportation, and installation of
7 concentrators. Total weight for some enclosed concentrated solar energy embodiments
8 (including exoskeleton and protected collector) is less than 20 kg per square meter of
9 concentrator.

10
11 **[0040]** The glasshouse structure is primarily fixed and immobile, and tracking systems
12 control and aim the less than one kg per square meter concentrators inside the structure in an
13 environment having relatively small wind forces.

14
15 **[0041]** In some embodiments, a commercial greenhouse is a suitable enclosure as
16 taught by the techniques described herein. Growers have determined that for many types of
17 plants, 1% less light reaching plants equals 1% less crop growth and hence profit. Greenhouse
18 designs are optimized to reduce cost, structural shading, glass reflective losses, and glass
19 transmission losses. In some usage scenarios, the structural shading, glass reflective losses, and
20 glass transmission losses cause a majority of lost sunlight. The Dutch Venlo design is relatively
21 efficient at reducing the losses. Options available in commercial greenhouses include low-
22 shading structural design, anti-reflective glass coatings (to reduce reflective losses), and low-iron
23 glass (to reduce transmissive losses).

24
25 **[0042]** In some embodiments, sunlight losses due to a glasshouse enclosure are less
26 than 20% at 33 degrees latitude without an anti-reflective coated glass. In some embodiments
27 using anti-reflective coated glass, losses are 13%. In some embodiments, techniques described
28 herein improve salvage value of a system in one or more of obsolescence, abandonment, and
29 destruction and/or damage due to storm, ice, corrosion, and earthquake events.

30
31 **[0043]** A commercial greenhouse has multiple uses and has, in some embodiments
32 and/or usage scenarios, a ready sale market for a greenhouse sold in place or for relocation. In
33 some embodiments, a greenhouse enclosure of a concentrated solar energy system is a
34 significant portion of the system cost. Resale value of the greenhouse, in some usage scenarios,
35 lowers overall risk of a solar energy project and/or reduces financing costs.

1 **[0044]** In some embodiments, long, continuous, fixed receivers are advantaged over
2 other systems to avoid complex and expensive mechanisms such as moving fluid joints or hoses
3 to connect the thermal medium system. In some embodiments and/or usage scenarios, selected
4 components (such as receivers or pipes) that are fixed during a tracking mode of operation are
5 permitted to move or are moved due to expansion and contraction of materials or for cleaning
6 during a maintenance mode of operation.

7
8 **[0045]** Thermal conduction and convection increase with wind speed, thus reducing
9 efficiency of solar thermal receivers. In some non-enclosed concentrated system approaches,
10 solar energy receivers are protected from environmental effects including heat loss and physical
11 damage by an at least partially transparent protective enclosure for each receiver. In some
12 enclosed embodiments, thermal energy receivers are enabled to minimize heat loss without using
13 an enclosure for each receiver.

14
15 **[0046]** In some embodiments, a greenhouse enclosure is a fixed cost and a significant
16 portion of overall system cost. Thus it is beneficial to have as much of the light that comes into
17 the greenhouse hit a mirror and reflect to a receiver as feasible during all seasons and all times of
18 day. A technique of tightly packing troughs, covering as much ground as feasible, is beneficial
19 when implementing a CSP system inside a greenhouse. In addition to more effectively using the
20 space enclosed by the greenhouse, such a technique also more effectively uses land area to
21 produce solar heat and power. Such a technique is enabled in part by concentrators inside a
22 greenhouse that are relatively inexpensive since the concentrators are not subject to significant
23 environmental insults such as wind, rain, and dust.

24
25 **[0047]** In some embodiments, such as some embodiments operating at high
26 temperatures (e.g. above 300 degrees Celsius), heat loss from receivers represents a significant
27 overall system cost. Thus, it is desirable to minimize receiver size to minimize surface area of
28 the receiver and thus to minimize heat losses from the receiver. In some embodiments, a shorter
29 focal length parabolic trough with a smaller aperture enables use of a smaller receiver, since
30 smaller lengths and angles reduce effects of manufacturing tolerances and of arc size of the sun.

31
32 **[0048]** One technique to tightly pack troughs to capture more incident light within an
33 enclosure, is to use more troughs and place them closer together to fill up the enclosed space.
34 This results in more total receiver length (since there are more troughs) and so more total
35 thermal loss and pumping cost. Such a system gathers more light in summer when the sun is
36 overhead and the troughs are in a horizontal position not shading each other, but collects no

1 more light in winter, due to shading, than a system with fewer troughs spaced far apart. Another
2 technique is to use longer focal length troughs with a wider aperture, again placed closer
3 together. This preserves total receiver length but uses larger receiver pipe to capture light from a
4 longer focal length mirrors and the larger aperture, thus increasing thermal loss or imposes
5 tighter tolerance on a concentrator to maintain focus, thus increasing cost and complexity. Some
6 of the embodiments described herein, when deployed in an east/west orientation and tracking
7 seasonal motion of the sun, use an asymmetric trough design wherein one side of a short focal
8 length trough is extended further than the other side in an extension area of the trough. In the
9 winter, when the troughs are angled up to face the winter sun, the extension areas are in shade
10 and gather no energy, but base portions of the short focal length troughs are in sun, and intercept
11 almost all available light. In the summer, when the troughs are more horizontal to face the high
12 in the sky sun, the short focal length center of the troughs enable capture of much of the light
13 and reflect that light to a small diameter receiver. The extension is now illuminated as well, and
14 captures the rest of the light that would otherwise be lost without the extension.

15
16 **[0049]** The extension section of the trough has a longer distance to the receiver and so
17 will not naturally focus as well. In the a relatively simple design, efficiency of the extension is
18 allowed to be lower than that of a remainder of a trough (such as 70%) since the extension is
19 used only for a fraction of the year and for a fraction of incident light. Alternately, a small
20 secondary reflector is used to capture light reflected from the extension that misses the receiver,
21 and reflect that light back to the receiver. A secondary reflector about two times the diameter of
22 the receiver enables capture of almost all the light from the extension. A secondary reflector
23 enables a receiver of a same size as without the extension and without increasing thermal losses.
24 In some embodiments, a partial insulator and convection shield are integrated with the secondary
25 reflector to reduce the thermal losses from the receiver.

26
27 **[0050]** In some embodiments of an asymmetric trough, e.g. having a larger aperture
28 than a base symmetric portion of the trough, greenhouse height is increased to make room for an
29 extension to clear the ground when the trough is vertical, thus increasing the cost, edge effect
30 shading, and design and/or manufacturing complexity of the greenhouse. A movable hinge
31 connecting the trough extension to the base portion of the trough enables a reduction of the
32 increase in the greenhouse height. During the winter, the trough is raised to face the sun and the
33 extension is moved on its hinge to remain essentially horizontal to the ground. Thus, the height
34 of the trough with a hinged extension during the winter is limited by the base portion of the
35 trough and not increased by the extension. During the summer, the trough is held more nearly

horizontal and the extension is returned to be a continuous extension of a (parabolic shape, e.g.) of the asymmetric trough.

[0051] Some embodiments orient troughs on a north/south axis and rotate the troughs to track daily motion of the sun. In such embodiments, a movably hinged extension on each side of the trough (a "top" extension and a "bottom" extension) are optionally used. During morning, a trough is held facing east toward the sun. The top extension is flipped behind the trough to reduce or eliminate shading of a longitudinally adjacent trough, while the bottom extension is held horizontal to the ground to prevent hitting the ground. Only the base portion of the trough is illuminated. At noon, the trough is horizontal to the ground, pointing at the sun high in the sky. The two extensions are in respective operating positions, providing an extended trough of a larger effective aperture. In evening, the trough is held vertical facing west, with the extensions held similarly to the morning. Thus at all times of day, most incident light (such as within a greenhouse) is captured by a concentrator.

INTEGRATION OF RECEIVER AND GREENHOUSE STRUCTURE

[0052] In some embodiments, a receiver and concentrator are suspended from superstructure of an enclosing greenhouse, enabling use of substantial support infrastructure of structure of the greenhouse. Lightweight receivers and troughs, hung from the greenhouse (e.g. roof structure, trusses, and/or end posts), are held in place and aimed with relatively small members that exert force mostly in tension, thus avoiding use of relatively larger members compared to structures held in place and moved with members in compression and subject to bending. The receiver is suspended at a fixed position relative to the greenhouse and the concentrator is suspended with its focal line held on the receiver but able to rotate around the receiver to track the daily and/or seasonal motion of the sun.

[0053] In some embodiments, a receiver pipe expands (such as by about ½ percent) when heated by thermal transport fluid transported in the receiver pipe. In some usage scenarios, a 500 foot pipe expands about two feet. In some embodiments, the receiver pipe is held in a fixed position at a "fixed" end of the pipe at one end of the greenhouse, and enabled, by hangers, to expand and contract along its length toward the other "non-fixed" end of the pipe. The hangers suspend the receiver pipe from superstructure of the greenhouse, and are designed so that when the receiver pipe is hot and at maximum extension (while operating), each hanger is vertical and the receiver pipe is horizontal. When the receiver pipe is cool and contracts (while

not operating), each hanger bottom is pulled slightly toward the fixed end of the receiver pipe and the receiver pipe is pulled slightly higher at the non-fixed end. When the receiver pipe is cool, each successive hanger is slight pulled in such that the hanger at the non-fixed end of the receiver pipe is pulled in (e.g. as much as two feet). For example, with approximately six foot hangers, the (cool) receiver pipe rises less than a foot relative to the other end of the receiver pipe. The concentrators are at a fixed distance and rise fall with the receiver pipe, thus preserving focus.

DESIGN OF HANGER, ROTATING JOINT AND BEARING

[0054] In some embodiments, a hanger with a rotating joint is held in place suspended from roof superstructure of a greenhouse. A receiver tube is rigidly connected to the hanger, thus supporting the receiver tube. The rotating joint is connected to the hanger with a bearing enabling the joint to rotate around the receiver tube. A trough is suspended from the rotating joint. All the weight of the joint and the trough is carried by the rotating joint, through a bearing and to the hanger and then up to the roof superstructure. The rotating joint is enabled to rotate for small adjustments during the day, through about $\frac{1}{2}$ turn from winter to summer, and another $\frac{1}{2}$ turn back from summer to winter. In some usage scenarios, during an entire lifetime of the joint, it rotates the equivalent of no more than 100 revolutions and never needs to rotate more than about 1rpm. The bearing and the rotating joint are designed to avoid shading the receiver tube and to withstand high temperatures (e.g. hundreds of degrees C) since the bearing and the joint are necessarily in close thermal proximity to a high temperature thermal medium and the receiver tube.

CONCENTRATED SOLAR ENERGY SYSTEM

[0055] Industrial scale concentrated solar power systems, in some embodiments, cover multiple acres of land, with large-scale systems practical in the hundreds of acres. Fig. 1 illustrates a perspective view of selected details of an embodiment of an enclosing greenhouse and an enclosed concentrated solar energy system for a small portion of a system. Greenhouse 25 has low internal shading and low cost. According to various embodiments, the greenhouses are less than an acre to hundreds of acres in size. Suitable commercial greenhouses are available with short lead times from various vendors. Additionally, in some usage scenarios, there is a market for used greenhouses, enabling relatively easier financing of large-scale concentrated

1 solar energy projects, such as described herein. Elements of the greenhouse include a roof
2 system with multiple peaks and gutters. The roof system is enabled to drain water efficiently
3 from the roof structure, to keep incident angles of sunlight relatively close to directly normal to
4 transparent roof material to reduce reflection, and to keep roof support members in compression.
5 Sidewalls of the greenhouse further enclose interior space of the greenhouse and have
6 transparent covering where sunlight is incident thereon and are optionally of any appropriate
7 material where little sunlight is incident. The greenhouse structure is enabled to keep most
8 wind, rain, and other environmental elements from the interior, and is optionally not entirely
9 weather tight. An optional fan driven overpressure filtration system (not illustrated) optionally
10 provides relatively clean pressurized air to the interior to further inhibit infiltration of dust and
11 other elements to the interior. The lack (or reduction) of dust reduces or eliminates a need to
12 clean concentrators (such as concentrators **27** and **28**), reducing operating costs and enabling use
13 of less robust and less scratch resistant reflective concentrator materials, in some usage scenarios
14 and/or embodiments. In some operating conditions, concentrators shade each other as illustrated
15 by front concentrator **27** in front of and shading concentrator rear **28**. In some embodiments,
16 concentrator troughs are much greater in length than width, with an aspect ratio of between 10-1
17 and 33-1 rather than the approximately 3-1 aspect ratio illustrated. In some embodiments, many
18 troughs are enclosed in a single greenhouse with one front trough **27** and all the rest rear troughs
19 such as **28**. In some embodiments, the troughs are aligned east/west, with troughs facing the
20 equator as illustrated, and track seasonal movement of the sun. In some embodiments, the
21 troughs are aligned north/south (not illustrated).

22
23 **[0056]** In some embodiments, all elements of the concentrated solar energy system are
24 located within a protected interior of a greenhouse. Greenhouse transparent cover material **53** is
25 glass or any material generally transparent to sunlight. The transparent cover optionally includes
26 an ultra violet (UV) blocking coating or film to enable use of plastics inside the greenhouse
27 (such as reflective plastic mirror films for the concentrator surfaces) that would otherwise break
28 down relatively rapidly. In some embodiments, solar receivers, such as implemented in part by
29 receiver pipe **12**, are held at somewhat fixed positions during sunlight collecting operation to
30 reduce a need for flexible joints carrying a thermal medium. The solar receivers are
31 interconnected through a series of thermally insulated pipes (such as pipe **8**). In a concentrated
32 solar thermal (CST) system, heated thermal medium is a primary output of the system and is fed
33 to an industrial process. In a direct electric system, such as a concentrated photo voltaic (CPV)
34 system, a thermal medium optionally provides cooling to PV cells or other aspects of the
35 receiver. Excess heat in the thermal medium of a CPV system is optionally used in an industrial

process. Measurement and control wires, power for motors, and various cabling is routed with the thermal medium pipes, in some CST and CPV embodiments.

[0057] In Fig. 1, line-focus solar receivers are illustrated and are suspended from receiver pipes **12** that are in turn suspended from the roof of the enclosing greenhouse. Line-focus solar concentrators are suspended from associated solar receivers so that the focal point of the concentrator is held relatively fixed on the receiver while the concentrator body remains free to rotate around the receiver (in one degree of freedom) to track daily and seasonal motions of the sun. The arrangement of relatively fixed receivers and concentrators that rotate around the receivers to track the sun is enabled, at least in part, by low weight of the concentrators and absence of wind forces on the concentrators.

[0058] Some trough solar concentrators (such as solar concentrator **27**), have a symmetric primary portion, e.g. built of symmetric facets (such as base trough section **6**), and a secondary section, e.g. built of one or more extension facets (such as extended trough section **7**). When held in a vertical position to aim at winter sun, the extension section is at bottom **26** of trough.

SHAPE OF TROUGH AND DEFINITIONS OF TERMS AND FORMULA

[0059] Fig. 2a illustrates a shape of a parabolic trough with an extension, such as an embodiment of an asymmetric (parabolic) trough. The shape of the parabolic trough is defined by the formula $y^2 = 4fa$. With example values described following, an example parabola is defined by the formula $y^2 = 5.8x$, where $-2.29 < x < 4$. A primary symmetric portion includes two symmetric base trough sections **6a** and **6b** referred to and illustrated collectively as base trough section **6**, and also sometimes referred to as (symmetric) base portion (of the trough). A secondary extended portion includes extended trough section **7**, and is, in some embodiments, a unilateral extension of the parabolic shape. Bottom of trough **26** is the edge of the trough that is closest to the ground when the trough is held vertical to face the sun low in the sky. Top of trough **30** is the edge of the trough that is furthest from the ground when the trough is held vertical. In some embodiments, bottom of trough **26** is the edge of extended trough section **7**, and is further from the ground when the trough is horizontal, pointed at the sun high in the sky (as illustrated in Fig. 2a, given an orientation of the trough such that construction line **34** is essentially horizontal to the ground). Trough focal length, illustrated by construction line **32** (e.g. having a value of 1.45 meters), is represented by the symbol/. A symmetric trough has an

1 *aperture* (referred to as a *base aperture* in a trough with an extension), defined by a construction
2 line between its two edges, such as illustrated by construction line **34** across the symmetric
3 portion and ending at construction line **44**, denoting intersection of the primary and the
4 secondary portions of the trough. Construction line **35** represents a half-portion of construction
5 line **34** (e.g. having a value of 2.29 meters). Construction line **33** indicates an *extended aperture*
6 (e.g. having a value of 6.29 meters) of the asymmetric trough (referred to simply as the *aperture*
7 where clear from context), including base trough section **6** and extended trough section **7**. In
8 some embodiments, extended trough section **7** is optionally movably connected to base trough
9 section **6**, is optionally enabled to change shape and/or is optionally enabled to change focus at
10 an intersection defined by construction line **44**. Construction line **48** defines an axis of
11 symmetry of the symmetric base portion of the trough and runs from the intersection of base
12 trough sections **6a** and **6b** through focal point **36**. Angles **37a** and **37b** are base *rim angles*
13 (sometimes referred to as the *base rim angle* for clarity) of the symmetric portion of the trough.
14 Angle **38** is the *extended rim angle* of the extended portion.
15

16 **[0060]** Fig. 2b illustrates various techniques for a secondary extension. In various
17 embodiments, extension **45** is a continuation of a parabolic shape of a primary portion, shares a
18 focal point with the primary portion, and is connected at an intersection defined by construction
19 line **44** either fixedly or by a movable hinge. In various embodiments, extension **46** is an
20 alternate shape, has a focal point that is distinct from the primary portion, and is connected at an
21 intersection defined by construction line **44** either fixedly or by a movable hinge. In various
22 embodiments, extension **47** is a flat shape, has a focal point that is distinct from the primary
23 portion, and is connected at an intersection defined by construction line **44** either fixedly or by a
24 movable hinge.
25
26

27 INCIDENT SUNLIGHT TRANSMISSION

28

29 **[0061]** In some embodiments, solar concentrators as large as will fit inside large
30 standard commercial greenhouses (e.g. roughly in a six meter aperture range), are used. Each
31 solar concentrator is associated with a drive mechanism and a solar receiver, thus increasing
32 concentrator size (correspondingly reducing how many are used in a particular area), and
33 reducing the number of the drive mechanisms and/or the solar receivers, reducing cost overall.
34 In various embodiments, one or more concentrators share a same drive mechanism.
35

1 **[0062]** Irradiance characterizes power of incident electromagnetic radiation (such as
2 sunlight) at a surface, per unit area. Some sunlight losses caused by the greenhouse enclosure
3 glass and structural shading are determined by comparing direct normal sunlight received inside
4 the greenhouse enclosure (interior) with unimpeded direct normal sunlight received outside the
5 greenhouse enclosure (exterior). In absolute terms, irradiance loss is highest at midday;
6 considered relatively, the irradiance loss is highest in mornings and evenings. Figs. 3A and 3B
7 illustrate selected details of an embodiment of a solar concentrator and solar receiver.

9 **[0063]** Fig. 3a illustrates paths of incident radiation **41** that has come through the
10 greenhouse enclosure and is reflected off base trough section **6** and extended trough section **7**.
11 Reflected light **42** from base trough section **6** is focused onto receiver pipe **12**. In some
12 embodiments, receiver pipe **12** diameter is sized so that most (such as 95% or more) of reflected
13 light from base trough section **6** hits receiver pipe **12**, taking into account angle of incident
14 radiation (due to the extent of the sun) and manufacturing tolerances. In some embodiments,
15 insulating jacket **20** is used to reduce heat loss from receiver pipe **12**. In some embodiments,
16 reflected light **43**, **49**, and **50** from extended trough section **7** is less well focused than reflected
17 light **42** from the base trough sections, such as with 95% of reflected light subtending twice the
18 area at the focal point as light reflected from the base trough sections due to the longer distances
19 from extended trough section **7** to receiver pipe **12**.

21 **[0064]** Fig. 3b illustrates in more detail a design of receiver pipe **12**, insulating jacket
22 **20**, and integrated secondary receiver **21**. In some embodiments, secondary reflector **21** is
23 implemented with a reflective coating applied to a portion of insulating jacket **20**. In some
24 embodiments, secondary reflector **21** is used to extended capture area of incident light from a
25 secondary portion without increasing size of receiver pipe **12**. Secondary reflector **21** reflects
26 light incident from extended trough section **7** onto receiver pipe **12**. In some embodiments,
27 secondary reflector **21** is approximately equal in cross section size as receiver pipe **12** and is
28 positioned above receiver pipe **12** as seen from extended trough section **7**. In some
29 embodiments, extended trough section **7** is designed so that its focal point is directly between
30 receiver pipe **12** and secondary reflector **21** so that half the light reflected from extended trough
31 section **7** directly hits receiver pipe **12** and half the light hits secondary reflector **21** and is then
32 reflected to receiver pipe **12**. Incident light **49** to top of secondary reflector **21** and **43** to bottom
33 of secondary reflector **21** reflect at various angles depending on the angle of incidence in paths
34 such as paths **51** to receiver pipe **12**.

1 SELECTED GREENHOUSE DETAILS

2
3 **[0065]** In some embodiments, a greenhouse includes roof peaks (such as roof peak **54**
4 of Fig. 4a) that in combination with included roof gutters (such as roof gutter **55a**) are enabled to
5 drain water over a large space and to angle transparent roof material relatively close to direct
6 normal to incident sunlight in summer and in winter. A roof system with peaks and gutters is
7 referred to as a "ridge and furrow" style roof, in some usage scenarios, and in some
8 embodiments, is a form of a "gutter-connected" roof system. The greenhouse includes support
9 columns (such as support column **29**). Some of the support columns are arranged around the
10 periphery of the greenhouse and others of the support columns are arranged within the
11 greenhouse. In some embodiments, the greenhouse includes support columns at every roof
12 gutter (such as support columns **57a**, and **57b** located at roof gutters **55a**, and **55b**, respectively,
13 of Fig. 4A). In alternate embodiments, every other support column is omitted (such as support
14 column **57a** being omitted) and trusses (such as truss **1**) are horizontal lattice girders. Roof
15 gutters without support columns are floating gutters (e.g. roof gutter **55a**). Some of the
16 embodiments that omit every other support column are implemented with a Venlo style
17 greenhouse. Various embodiments suspend pipes **8** and receiver pipes **12** from trusses **1** or
18 horizontal lattice girders. Various embodiments suspend pipes from trusses or horizontal lattice
19 girders and further suspend receivers from pipes.

20
21
22 SELECTED MOUNTING AND CONTROL MECHANISM DETAILS

23
24 **[0066]** Figs. 4a and 4b illustrate a parabolic trough with a fixed unilateral extension
25 including extended trough section **7** enclosed in greenhouse **25** held in a horizontal (summer)
26 position and a vertical (winter) position respectively. A rotating suspension mechanism and a
27 receiver pipe are outlined by construction line **52** and illustrated in more detail in Figs. 6a and
28 6b. Suspension hanger **16** is suspended from greenhouse truss **1** by suspension members **2**.
29 Base trough section **6** is suspended from suspension hanger **16** by fixed base trough suspension
30 members **4** and fixed extension suspension member **5f** that hold the trough at a fixed distance
31 from the receiver pipe, with a focal line of the trough on (or concentric with) the receiver pipe.
32 Suspension members **4** are connected to base trough section **6** and extended trough section **7**
33 with trough section connectors **15**. Insulated pipe **8** connects the trough receiver pipe to a next
34 trough receiver pipe to complete a thermal fluid circuit.

1 **[0067]** Top of trough **30** and bottom of trough **26** in a maximum vertical winter
2 position determine a height requirement for a greenhouse such that bottom of trough **26** does not
3 hit floor of greenhouse **39** and top of trough **30** does not interfere with truss **1**.

4
5 **[0068]** In some embodiments, counterweight **14** is used to balance a trough so that its
6 resting position is at least as vertical as the most vertical position used for solar energy collecting
7 operation, enabling positioning the trough through all its operating positions by positioning
8 member **9** that is shortened or lengthened as required by winch **11**. In some embodiments, all
9 support and positioning members **2, 4, 5f** and **9** are designed to operate only in tension. In some
10 embodiments, some or all of support and positioning members **2, 4, 5f** and **9** are optionally
11 flexible members such as wire, monofilament, or rigid members with low strength under
12 compression and torsion. In some embodiments, gear ratio and torque requirements of winch **11**
13 are minimized by connecting positioning member **9** far from an axis of rotation of the trough. In
14 some embodiments, positioning errors due to gear lash and due to gear and other member
15 manufacturing tolerances, are minimized because positioning member **9** is always held in
16 tension when the trough is operational, and gravity is sufficient as a counterforce in positioning
17 the trough since wind is minimized inside enclosure **25**.

18
19
20 SELECTED DETAILS OF A MOVABLE HINGED EXTENSION
21

22 **[0069]** Figs. 5a and 5b illustrate, respectively, a trough with a movable extension,
23 otherwise similar to, respectively, the trough with the fixed extension illustrated in Figs. 4a and
24 4b. In Figs. 5a and 5b, section connector **15**, at the intersection of base trough sections **6** and
25 extended trough section **7**, is conceptually replaced with hinged section connector **13**. Fixed
26 extension suspension member **5f** of Figs. 4a and 4b, is conceptually replaced by movable
27 extension suspension member **5m** of Figs. 5a and 5b. In some embodiments, movable extension
28 suspension member **5m** is a rigid bar fixedly connected to the outside edge of extended trough
29 section **7** and coupled (e.g. via direct mechanical connection or via one or more intermediate
30 mechanical members) to hanger **16** to enable sliding. Extension stop member **10** is fixedly
31 connected to truss **1** and connected to extended trough section **7** to enable sliding. In a summer
32 position illustrated in Fig. 5a (and in any position where the extension is operational) movable
33 extension suspension member **5m** slides to a stop at hanger **16**, and holds extended trough
34 section **7** in an operating position as an extension of base trough section **6**, while extension stop
35 member **10** slides free and does not influence the position of extended trough section **7**. In a
36 winter position illustrated in Fig. 5b (and in any position where the extension is stowed and non-

operational), movable extension suspension member **5m** slides free and does not influence the position of extended trough section **7**, while extension stop member **10** slides to a stop at the edge of section **7**, and holds extended trough section **7** in its non-operation (stowed) position above floor **39** of greenhouse **25**. Construction line **40** illustrates the lowest point touched by any part of the trough mechanism with the movable extension and so the distance between construction line **40** and greenhouse floor **39** represents a reduction in greenhouse height enabled by the movable hinged extension compared to an extension that is not movable (e.g. fixed).

[0070] In some embodiments with a movable extension section, counterweight **14** is sized so that the center of gravity of a trough system provides a countervailing force against positioning member **9**, when movable extension support member **5m** is engaged, as well as when extension stop member **10** is engaged, and is sufficient to counter any forces that in some usage scenarios would otherwise raise bottom of trough **26**.

[0071] In some embodiments, rigid sliding movable extension support member **5m** is implemented with a flexible member (such as wire or monofilament) of a length determined to hold extended trough section **7** in proper operating position when under tension (as held by gravity) and that is slack and exerts no influence on position of extended trough section **7** when extended trough section **7** is held in a stowed position by extension stop member **10**.

[0072] Figs. 6a and 6b illustrate details of an area outlined on Figs 4a, 4b, 5a, and 5b by construction line **52**. Fig. 6a is a perspective view from the side of hanger **16** that rotating joint **3** is mounted on, while Fig 6b is a perspective view from the opposite side. A connecting fastener (not illustrated) is used at location **31** to connect hanger suspension members **2** and trough suspension members **4** to hanger **16** and rotating joint **3** respectively. Receiver pipe **12** is suspended and fixedly connected to hanger **16**. Movable extension suspension member **5m** is connected to rotating joint **3** through sliding connector **17** (used for movable hinged extension embodiments). In Fig. 6a, movable extension support member **5m** is in the state where extension support member stop **18** is not engaged with sliding connector **17**, and so movable extension support member **5m** is not influencing the position of the extension trough section. This is a non-operational position of the extension trough section (e.g. during winter or maintenance). In Fig. 6b, movable extension support member **5m** is in the state where extension support member stop **18** is not engaged with sliding connector **17** and so movable extension support member **5m** is holding the position of extension trough section. This an operational position of the extension trough section (e.g. during summer). In an embodiment with a fixed extension, movable support member **5m** is held fixed with its stop **18** engaged. In some

embodiments, rotating joint **3** is connected to hanger **16** with a bearing (not illustrated in detail), enabling rotating joint **3** to rotate around hanger **16**.

[0073] Fig. 7 illustrates certain details of a parabolic trough with an extension, a receiver pipe, and an associated suspension mechanisms in a context free of other details to make certain details easier to understand. Extension suspension member **5** is representative of embodiments with fixed extension suspension member **5f** and movable extension suspension member **5m**, as appropriate.

[0074] Figs. 8a and 8b illustrate certain details of receiver pipe **12**, insulating jacket **20**, secondary reflector **21**, hanger **16**, and various light paths to make certain details easier to understand. Incident light rays (**22i**, **23i**, and **24i**) are reflected off of secondary reflector **21** as respective reflected light rays (**22r**, **23r**, and **24r**).

[0075] In some embodiments, construction and suspension of a trough is accomplished by pinning together various elements, including suspension members **2**, **4**, and **5**, hanger **16**, base trough section **6** and extended trough section **7**. Each segment of the concentrator is made from pre-formed mirror surfaces having sufficient internal structure to hold shape and curvature without use of other elements, while under the force of gravity and small forces imposed by suspension and positioning. The concentrators are enabled for inside use, protected by a greenhouse, and so are not strong enough to withstand wind force or environmental elements such as rain and dust. Suspension members are either light rigid members or wires. In either case, the suspension members connect to the concentrator surface, joint, hanger, or roof superstructure with pins that are readily insertable for assembly and readily removable for service.

GRAPHS COMPARING PERFORMANCE OF STANDARD TROUGH TO TROUGH WITH EXTENSION

[0076] Figs. 9a and 9b are graphs of a focal point and a shape of a mirror of a symmetric trough without an extension, and an asymmetric trough with an extension, respectively. Both troughs have an aperture of 5.8 meters. Figs 10a and 10b are, respectively, plots of percent of energy received at a receiver pipe for each trough. For the symmetric trough (with a relatively long focal length as illustrated in Fig. 10a), a receiver pipe of 50mm diameter is used to achieve an intercept factor above 80% across the surface of the mirror while

1 minimizing receiver pipe diameter. In Fig 10b, a smaller receiver pipe of 40mm is used, because
2 the relatively shorter focal length of the asymmetric trough enables a higher average intercept
3 factor with a smaller, and so more efficient, receiver pipe. The mirror of the extension section
4 (termed the secondary in the plot) falls below an 80% intercept factor at its outside edge, but this
5 edge is only used in summer, and the overall intercept factor of the asymmetric trough remains
6 better than that of the symmetric trough. In Fig. 11a, performances of the symmetric and the
7 asymmetric troughs are plotted together as a shade line progresses across the mirror. The
8 asymmetric trough starts producing useful energy sooner as the shade line moves off the mirror,
9 and in all positions of the shade line, outperforms the symmetric trough. Fig. 11b is a plot of the
10 same data as a function of percent of the mirror surface that is shaded, and again demonstrates
11 that the asymmetric trough outperforms the symmetric trough.

14 SELECTED EMBODIMENT DETAILS

16 **[0077]** In various embodiments and/or usage scenarios, the illustrated embodiments are
17 related to each other. For example, in some embodiments, movable extension suspension
18 member **5m** of Figs. 5a, 5b, 6a, and 6b, is appropriate for use in various embodiments as an
19 implementation of fixed extension suspension member **5f** of Figs. 4a and 4b.

21 **[0078]** While the forgoing embodiments are described as having roof systems with
22 peaks and gutters, other embodiments use alternate roof systems, such as peaked, arched,
23 mansard, and Quonset-style roof systems, as well as variations and combinations thereof. In
24 various embodiments, a partially transparent protective enclosure (such as a glasshouse or a
25 greenhouse) uses glass to provide the transparency, and other embodiments use alternative
26 transparent materials such as plastic, polyethylene, fiberglass-reinforced plastic, acrylic,
27 polycarbonate, or any other material having suitable transparency to sunlight and sufficient
28 strength (in combination with a supporting framework) to provide environmental protection.

CONCLUSION

[0079] Certain choices have been made in the description merely for convenience in preparing the text and drawings and unless there is an indication to the contrary the choices should not be construed per se as conveying additional information regarding structure or operation of the embodiments described. Examples of the choices include: the particular organization or assignment of the designations used for the figure numbering and the particular organization or assignment of the element identifiers (the callouts or numerical designators, e.g.) used to identify and reference the features and elements of the embodiments.

[0080] The words "includes" or "including" are specifically intended to be construed as abstractions describing logical sets of open-ended scope and are not meant to convey physical containment unless explicitly followed by the word "within."

[0081] Although the foregoing embodiments have been described in some detail for purposes of clarity of description and understanding, the invention is not limited to the details provided. There are many embodiments of the invention. The disclosed embodiments are exemplary and not restrictive.

[0082] It will be understood that many variations in construction, arrangement, and use are possible, consistent with the description, and are within the scope of the claims of the issued patent. The names given to elements are merely exemplary, and should not be construed as limiting the concepts described. Also, unless specifically stated to the contrary, value ranges specified, maximum and minimum values used, or other particular specifications, are merely those of the described embodiments, are expected to track improvements and changes in implementation technology, and should not be construed as limitations.

[0083] Functionally equivalent techniques known in the art are employable instead of those described to implement various components, sub-systems, operations, functions, or portions thereof.

[0084] The embodiments have been described with detail and environmental context well beyond that required for a minimal implementation of many aspects of the embodiments described. Those of ordinary skill in the art will recognize that some embodiments omit disclosed components or features without altering the basic cooperation among the remaining elements. It is thus understood that much of the details disclosed are not required to implement

1 various aspects of the embodiments described. To the extent that the remaining elements are
2 distinguishable from the prior art, components and features that are omitted are not limiting on
3 the concepts described herein.

4
5 **[0085]** All such variations in design are insubstantial changes over the teachings
6 conveyed by the described embodiments. It is also understood that the embodiments described
7 herein have broad applicability to other applications, and are not limited to the particular
8 application or industry of the described embodiments. The invention is thus to be construed as
9 including all possible modifications and variations encompassed within the scope of the claims
10 of the issued patent.

WHAT IS CLAIMED IS:

- 1 1. A system comprising:
2 an at least partially enclosing structure establishing an interior region
3 comprising a selectively protected environment relative to an exterior
4 region, at least a section of the structure comprising portions enabling
5 transmittance of solar radiation from a sun; and
6 within the interior region, a line-focus concentrator enabled to selectively rotate
7 about a focal line to concentrate thereon a fraction of the solar radiation,
8 wherein the line-focus concentrator comprises a longitudinally
9 bilaterally symmetric primary portion and a secondary portion
10 comprising at least one lateral extension movably coupled to the
11 primary portion.
- 1 2. The system of claim 1, wherein the line-focus concentrator is an asymmetric line-focus
2 concentrator and the at least one lateral extension comprises a unilateral extension.
- 1 3. The system of claim 1, wherein the primary portion in cross section at least approximates a
2 particular curvature, wherein the secondary portion comprises a first lateral extension
3 and a second lateral extension, each lateral extension being independently articulated
4 with a respective side of the primary portion, each lateral extension being enabled to
5 selectively continue the particular curvature of the primary portion, and the line-focus
6 concentrator is a multi-mode line-focus concentrator enabled to be selectively
7 configured in various modes comprising a morning asymmetric line-focus concentrator,
8 a midday symmetric line-focus concentrator, and an afternoon asymmetric line-focus
9 concentrator.
- 1 4. The system of claim 2, wherein the asymmetric line-focus concentrator is enabled to be
2 selectively rotated at least in accordance with seasonal changes in declination of the sun.
- 1 5. The system of claim 3, wherein, in accordance with daily changes in zenith angle of the sun,
2 the multi-mode line-focus concentrator is enabled to be selectively configured in a
3 particular one of the various modes and selectively rotated.

- 1 6. The system of claim 1, wherein the rotation is in accordance with a predefined solar tracking
2 strategy.
- 1 7. The system of claim 6, wherein the predefined solar tracking strategy comprises control of
2 rotational positioning at least in part via closed-loop feedback.
- 1 8. The system of claim 7, wherein the closed-loop feedback uses at least one implementation
2 technology selected from: mechanical, electromechanical, analog circuitry, sampled
3 data, digital logic, stored-program digital-processor, continuous-time, or discrete-time.
- 1 9. The system of claim 6, wherein the predefined solar tracking strategy comprises control of
2 rotational positioning at least in part via a timer.
- 1 10. The system of claim 9, wherein the timer uses at least one implementation technology
2 selected from: mechanical, electromechanical, analog circuitry, sampled data, digital
3 logic, stored-program digital-processor, continuous-time, or discrete-time.
- 1 11. The system of claim 6, wherein the predefined solar tracking strategy comprises enabling
2 rotating the line-focus concentrator at least at predetermined intervals to reduce an angle
3 of incidence of rays of the sun with respect to a vector normal of the line-focus
4 concentrator.
- 1 12. The system of claim 6, wherein the predefined solar tracking strategy comprises enabling at
2 least occasionally rotating the line-focus concentrator to reduce an angle of incidence of
3 rays of the sun with respect to a vector normal of the line-focus concentrator.
- 1 13. The system of claim 7, wherein the predefined solar tracking strategy comprises enabling
2 rotating the line-focus concentrator as determined by the closed-loop feedback to at least
3 quasi-continuously reduce an angle of incidence of rays of the sun with respect to a
4 vector normal of the line-focus concentrator.
- 1 14. The system of claim 1, wherein the primary portion comprises at least one reflective surface
2 that collectively in cross section at least approximates a segment of a parabolic curve.
- 1 15. The system of claim 1, wherein the primary portion comprises a continuous reflective
2 surface that in cross section is a segment of a parabolic curve.

- 1 16. The system of claim 1, wherein the primary portion comprises a plurality of reflective
2 surfaces corresponding in cross section to respective segments of a parabolic curve.
- 1 17. The system of claim 1, wherein the primary portion comprises a plurality of reflective
2 facets.
- 1 18. The system of claim 1, wherein each lateral extension comprises at least one reflective
2 surface and each lateral extension in cross section at least approximates a segment of a
3 parabolic curve.
- 1 19. The system of claim 1, wherein each lateral extension of the secondary portion is enabled to
2 rotate about a respective longitudinal axis that is parallel to the focal line.
- 1 20. The system of claim 1, further comprising a respective hinge enabling each lateral extension
2 of the secondary portion to rotate about a longitudinal axis that is parallel to the focal
3 line.
- 1 21. The system of claim 1, wherein each lateral extension of the secondary portion is
2 respectively articulated to the primary portion.
- 1 22. The system of claim 21, wherein the respective articulation is enabled by at least one
2 respective movable joint.
- 1 23. The system of claim 2, wherein the unilateral extension of the secondary portion is enabled
2 to be moved into a position selected from at least one respective operational position and
3 at least one respective stowed position.
- 1 24. The system of claim 23, wherein the at least one respective stowed position comprises a
2 partially retracted position.
- 1 25. The system of claim 23, wherein during at least a first interval of the year the secondary
2 portion is enabled to be placed in the at least one operational position and during at least
3 a second interval of the year the secondary portion is enabled to be placed in the at least
4 one stowed position.

1 26. The system of claim 1, wherein the secondary portion comprises a first lateral extension of
2 the primary portion and a second lateral extension of the primary portion, during a first
3 interval of the day the first lateral extension is enabled to be placed in a respective
4 operational position and the second lateral extension is enabled to be placed in a
5 respective stowed position, during a last interval of the day the first lateral extension is
6 enabled to be placed in a respective stowed position and the second lateral extension is
7 enabled to be placed in a respective operational position, and during a middle interval of
8 the day the first lateral extension and the second lateral extension are enabled to be
9 placed in their respective operational positions.

1 27. The system of claim 23, wherein the primary portion in cross section at least approximates a
2 particular curvature and in the at least one operational position the at least one lateral
3 extension of the secondary portion is enabled to act as a continuation of the particular
4 curvature of the primary portion and the at least one lateral extension of the secondary
5 portion shares the same focal line as the primary portion.

1 28. The system of claim 23, wherein the primary portion is a first line-focus concentrator, the
2 focal line is a first focal line, and in the at least one operational position the secondary
3 portion is enabled to act as a second line-focus concentrator having a second focal line.

1 29. The system of claim 28, further comprising:
2 within the interior region, a line-focus receiver enabled to operate coincident to the first
3 focal line and a reflector enabled to operate coincident to the second focal line;
4 and
5 wherein the reflector is enabled to redirect at least a portion of the solar radiation
6 received from the second line-focus concentrator to the line-focus receiver.

1 30. The system of claim 28, further comprising:
2 within the interior region, a line-focus receiver enabled to operate coincident to the first
3 focal line and a reflector enabled to operate coincident to the second focal line;
4 and
5 wherein the second line-focus concentrator and the reflector are collectively enabled to
6 focus at least a portion of the solar radiation received from the second line-focus
7 concentrator onto the line-focus receiver.

- 1 31. The system of claim 1, further comprising: within the interior region, a line-focus receiver
2 enabled to operate coincident to the focal line and stationary with respect to the
3 structure.
- 1 32. The system of claim 1, wherein the rotation about the focal line of at least the primary
2 portion is at a radial distance specified by a focal length.
- 1 33. The system of claim 32, wherein the focal length is a nominal focal length and the radial
2 distance has an associated variance from the nominal focal length in view of one or
3 more manufacturing, installation, maintenance, and operational tolerances.
- 1 34. A system comprising:
2 an at least partially enclosing structure establishing an interior region
3 comprising a selectively protected environment relative to an exterior
4 region, at least a section of the structure comprising portions enabling
5 transmittance of solar radiation from a sun; and
6 within the interior region, a line-focus concentrator enabled to selectively rotate
7 about a focal line to concentrate thereon a fraction of the solar radiation,
8 wherein the line-focus concentrator comprises a longitudinally
9 bilaterally symmetric primary portion and a secondary portion
10 comprising a unilateral extension of the primary portion.
- 1 35. The system of claim 34, wherein the unilateral extension of the secondary portion is
2 inflexibly joined to the primary portion.
- 1 36. The system of claim 34, wherein the unilateral extension of the secondary portion is an
2 integral appendage of the primary portion.
- 1 37. The system of claim 34, wherein the primary portion in cross section at least approximates a
2 particular curvature, the unilateral extension of the secondary portion is rigidly held to
3 continue the particular curvature of the primary portion, and the unilateral extension of
4 the secondary portion shares the same focal line as the primary portion.
- 1 38. The system of claim 34, wherein the rotation about the focal line of at least the primary
2 portion is at a radial distance specified by a focal length.

1 39. The system of claim 38, wherein the focal length is a nominal focal length and the radial
2 distance has an associated variance from the nominal focal length in view of one or
3 more manufacturing, installation, maintenance, and operational tolerances.

1 40. A line-focus concentrator comprising:
2 a longitudinally bilaterally symmetric first primary reflector;
3 a second primary reflector comprising a unilateral extension of the first primary
4 reflector; and
5 wherein the line-focus concentrator is enabled to selectively rotate about a focal line to
6 concentrate thereon a fraction of solar radiation from a sun.

1 41. The system of claim 40, wherein the rotation about the focal line of at least the first primary
2 reflector is at a radial distance specified by a focal length.

1 42. The system of claim 41, wherein the focal length is a nominal focal length and the radial
2 distance has an associated variance from the nominal focal length in view of one or
3 more manufacturing, installation, maintenance, and operational tolerances.

1 43. A line-focus concentrator comprising:
2 a longitudinally bilaterally symmetric portion at least approximating a particular
3 parabolic curvature;
4 a secondary portion comprising at least one lateral extension movably coupled
5 to the first primary portion, each lateral extension enabled in at least a
6 first mode to be placed in an operational position to continue the
7 curvature of the primary portion and share with the primary portion a
8 common focal line, each lateral extension enabled further in at least a
9 second mode to be placed in a stowed position; and
10 wherein the line-focus concentrator is enabled to selectively rotate about the
11 common focal line to concentrate thereon a fraction of solar radiation
12 from a sun.

1 44. The line-focus concentrator of claim 43, wherein the rotation about the focal line of at least
2 the longitudinally bilaterally symmetric portion is at a radial distance specified by a
3 focal length.

- 1 45. The line-focus concentrator of claim 44, wherein the focal length is a nominal focal length
2 and the radial distance has an associated variance from the nominal focal length in view
3 of one or more manufacturing, installation, maintenance, and operational tolerances.
- 1 46. A system comprising:
2 an at least partially enclosing structure establishing an interior region
3 comprising a selectively protected environment relative to an exterior
4 region, at least a section of the structure comprising portions enabling
5 transmittance of solar radiation from a sun; and
6 within the interior region, a longitudinally bilaterally asymmetric line-focus
7 concentrator enabled to selectively rotate about a focal line to
8 concentrate thereon a fraction of the solar radiation, wherein the line-
9 focus concentrator comprises a longitudinally bilaterally symmetric
10 primary portion and a secondary portion fixed to the primary portion.
- 1 47. The system of claim 46, wherein the rotation about the focal line of at least the primary
2 portion is at a radial distance specified by a focal length.
- 1 48. The system of claim 47, wherein the focal length is a nominal focal length and the radial
2 distance has an associated variance from the nominal focal length in view of one or
3 more manufacturing, installation, maintenance, and operational tolerances.
- 1 49. The system of claim 46, further comprising, within the interior region, a line-focus solar
2 energy receiver enabled to operate coincident to the focal line, and wherein during a
3 tracking mode of operation, the focal line is stationary with respect to the structure, and
4 the line-focus concentrator is enabled to track relative motion of the sun and to maintain
5 concentration of a fraction of the solar radiation onto the line-focus solar energy
6 receiver.
- 1 50. The system of claim 46, wherein one or more of the primary portion and the secondary
2 portion are segmented.

- 1 51. A system comprising:
2 an at least partially enclosing structure establishing an interior region
3 comprising a selectively protected environment relative to an exterior
4 region, at least a section of the structure comprising portions enabling
5 transmittance of solar radiation from a sun; and
6 within the interior region, a line-focus concentrator enabled to selectively rotate
7 about a first focal line, wherein the line-focus concentrator comprises a
8 longitudinally bilaterally symmetric primary portion enabled to
9 concentrate a first fraction of the solar radiation along the first focal line
10 and a secondary portion enabled to concentrate a second fraction of the
11 solar radiation along a second focal line, the second portion comprising
12 at least one lateral extension of the primary portion.
- 1 52. The system of claim 51, further comprising a line-focus receiver enabled to operate
2 coincident with the first focal line.
- 1 53. The system of claim 51, wherein the rotation about the focal line of at least the primary
2 portion is at a radial distance specified by a focal length.
- 1 54. The system of claim 53, wherein the focal length is a nominal focal length and the radial
2 distance has an associated variance from the nominal focal length in view of one or
3 more manufacturing, installation, maintenance, and operational tolerances.
- 1 55. The system of claim 53, wherein the focal length is a first nominal focal length and
2 corresponds to the first focal line, a second nominal focal length corresponds to the
3 second focal line, and the first and the second nominal focal lengths are distinct.
- 1 56. The system of claim 51, wherein the focal length is a first nominal focal length and
2 corresponds to the first focal line, a second nominal focal length corresponds to the
3 second focal line, and the first and the second nominal focal lengths are equal.
- 1 57. The system of claim 51, wherein the first focal line and the second focal line are parallel to
2 each other and distinct.
- 1 58. The system of claim 51, wherein the first focal line and the second focal line coincide.

- 1 59. The system of claim 52, further comprising a reflector enabled to redirect to the line-focus
2 receiver at least a portion of the solar radiation concentrated along the second focal line
3 by the secondary portion.
- 1 60. A system comprising:
2 means for establishing an at least partially enclosed interior region comprising a
3 selectively protected environment relative to an exterior region;
4 means for transmittance of solar radiation from a sun to the interior region;
5 within the interior region, means for solar energy receiving at each of a plurality of
6 interior region focal lines; and
7 within the interior region, means for line-focus concentrating a fraction of the solar
8 radiation transmitted on the interior region focal lines while concurrently
9 tracking relative motion of the sun and maintaining the interior region focal
10 lines stationary.
- 1 61. The system of claim 60, wherein the means for establishing is a greenhouse comprising a
2 roof superstructure comprising the means for transmittance.
- 1 62. The system of claim 60, wherein the means for line-focus concentrating weighs less than
2 two kg per square meter of line-focus concentrating area.
- 1 63. The system of claim 62, wherein the system comprises structural metal weighing less than
2 20 kg per square meter of line-focus concentrating area.
- 1 64. The system of claim 60, wherein the means for solar energy receiving is enabled to locally
2 convert at least a portion of the solar radiation to electricity.
- 1 65. The system of claim 60, wherein the means for solar energy receiving comprises
2 interconnected piping carrying a thermal transport medium heated by the means for
3 solar energy receiving.
- 1 66. The system of claim 65, wherein the heated thermal transport medium is used by an
2 industrial process.

1 67. The system of claim 60, wherein the means for transmittance comprises a UV blocking
2 coating and the means for line-focus concentrating comprises reflective plastic mirror
3 film.

1 68. The system of claim 63, wherein the means for line-focus concentrating comprises line-
2 focus concentrators of greater than six meters aperture.

1 69. The system of claim 60, wherein the means for line-focus concentrating comprises a Fresnel
2 reflector.

1 70. The system of claim 60, wherein the means for line-focus concentrating comprises a
2 plurality of heliostats.

1 71. The system of claim 60, wherein the means for line-focus concentrating comprises a
2 plurality of monolithic reflectors.

1 72. A system comprising:
2 an at least partially enclosing structure establishing an interior region comprising a
3 selectively protected environment relative to an exterior region, at least a section
4 of the structure comprising portions enabling transmittance of solar radiation
5 from a sun;
6 within the interior region, a plurality of line-focus solar concentrators having a
7 respective plurality of corresponding focal lines;
8 within the interior region, a respective plurality of solar energy receivers, each of the
9 receivers corresponding to a respective one of the focal lines; and
10 wherein for each focal line and during a tracking mode of operation, the focal line is
11 stationary with respect to the structure, and the corresponding concentrator is
12 enabled to track relative motion of the sun and maintain focus of a
13 corresponding fraction of the solar radiation transmitted through the portions
14 onto the receiver corresponding to the focal line.

1 73. The system of claim 72, wherein the structure is a greenhouse comprising a roof
2 superstructure comprising the portions.

1 74. The system of claim 72, wherein each concentrator weighs less than two kg per square
2 meter of concentrator area.

- 1 75. The system of claim 74, wherein the system comprises structural metal weighing less than
2 20 kg per square meter of concentrator area.
- 1 76. The system of claim 72, wherein each receiver is enabled to locally convert at least a portion
2 of the solar radiation to electricity.
- 1 77. The system of claim 72, wherein the receivers are interconnected with piping carrying a
2 thermal transport medium heated by the receivers.
- 1 78. The system of claim 77, wherein the heated thermal transport medium is used by an
2 industrial process.
- 1 79. The system of claim 72, wherein the portions comprise a UV blocking coating and the
2 concentrators comprise reflective plastic mirror film.
- 1 80. The system of claim 75, wherein each concentrator has an aperture of greater than six
2 meters.
- 1 81. The system of claim 72, wherein each line-focus concentrator is a Fresnel reflector.
- 1 82. The system of claim 72, wherein each line-focus concentrator comprises a plurality of
2 heliostats.
- 1 83. The system of claim 72, wherein each line-focus concentrator is a monolithic reflector.
- 1 84. The system of claim 72, wherein for each focal line the relative motion tracking comprises
2 rotating the corresponding concentrator about the respective stationary focal line.
- 1 85. The system of claim 73, wherein the concentrators are suspended from structural members
2 of the roof superstructure.
- 1 86. The system of claim 73, wherein the concentrators are suspended from piping suspended
2 from the roof superstructure.
- 1 87. The system of claim 72, wherein the interior region is maintained at a positive air pressure
2 relative to the external region.

- 1 88. The system of claim 73, wherein the greenhouse is a Venlo-type greenhouse.
- 1 89. The system of claim 74, wherein each concentrator comprises a foam core sandwich
2 backing and a reflective material.
- 1 90. The system of claim 72, wherein each receiver is enabled to heat a thermal transport
2 medium.
- 1 91. The system of claim 77, wherein the receivers are suspended with their weight substantially
2 borne by the piping.
- 1 92. The system of claim 72, wherein the focal lines and their corresponding receivers and
2 concentrators are arranged in at least one linear array.
- 1 93. The system of claim 73, wherein the greenhouse is a ridge and furrow greenhouse.
- 1 94. The system of claim 93, wherein the focal lines and their corresponding receivers and
2 concentrators are arranged in a plurality of parallel linear arrays, each linear array
3 corresponding to a roof ridge of the greenhouse.
- 1 95. The system of claim 77, wherein the concentrators are suspended with their weight
2 substantially borne by the piping.
- 1 96. The system of claim 72, wherein for each focal line the relative motion tracking comprises
2 rotating a focal axis of the corresponding concentrator about the respective stationary
3 focal line.
- 1 97. The system of claim 85, wherein the structural members are trusses.
- 1 98. The system of claim 76, wherein each receiver comprises a conversion technology selected
2 from photovoltaic cells and a Stirling cycle engine.
- 1 99. The system of claim 91, wherein the piping is suspended from the roof superstructure.

- 1 100. The system of claim 88, wherein the focal lines and their corresponding receivers and
2 concentrators are arranged in a plurality of parallel linear arrays, each linear array
3 corresponding to at least two roof ridges of the greenhouse.
- 1 101. The system of claim 72, wherein each of the concentrators is mechanically connected to its
2 corresponding receiver by a respective group of rigid members.
- 1 102. The system of claim 89, wherein the reflective material is a material selected from
2 reflective film and thin-gauge aluminum foil.
- 1 103. The system of claim 72, wherein the selectively protected environment is at least partially
2 protected from one or more of wind, dirt, and precipitation.
- 1 104. The system of claim 72, further comprising a fan driven overpressure filtration system
2 enabled to force filtered air into the structure.
- 1 105. The system of claim 85, wherein the structural members comprise horizontal lattice
2 girders.
- 1 106. A method comprising:
2 establishing an at least partially enclosed interior region comprising a selectively
3 protected environment relative to an exterior region;
4 admitting solar radiation from a sun to the interior region;
5 within the interior region, receiving solar energy at each of a plurality of interior region
6 focal lines; and
7 within the interior region, line-focus concentrating a fraction of the solar radiation
8 admitted on the interior region focal lines while concurrently tracking relative
9 motion of the sun and maintaining the interior region focal lines stationary.
- 1 107. The method of claim 106, wherein the establishing is via a greenhouse comprising a roof
2 superstructure that enables the admitting.
- 1 108. The method of claim 106, further comprising locally converting at least a portion of the
2 solar energy to electricity.

1 109. The method of claim 106, further comprising heating a thermal transport medium with at
2 least a portion of the concentrated solar energy.

1 110. The method of claim 109, further comprising using the heated thermal transport medium in
2 an industrial process.

1 111. The method of claim 106, wherein the line-focus concentrating is via a Fresnel reflector.

1 112. The method of claim 106, wherein the line-focus concentrating is via a plurality of
2 heliostats.

1 113. The method of claim 106, wherein the line-focus concentrating is via a monolithic
2 reflector.

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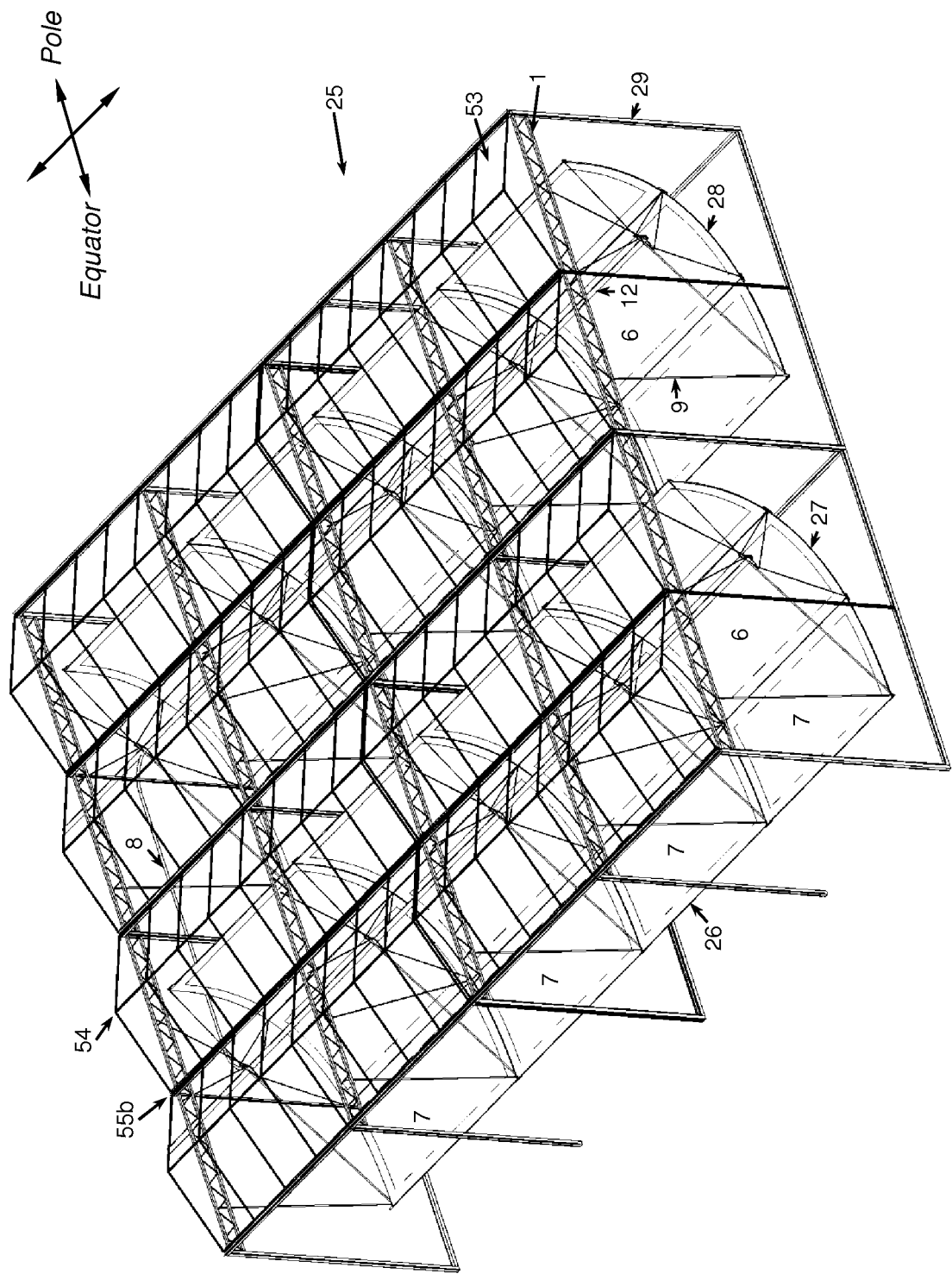


Fig. 1

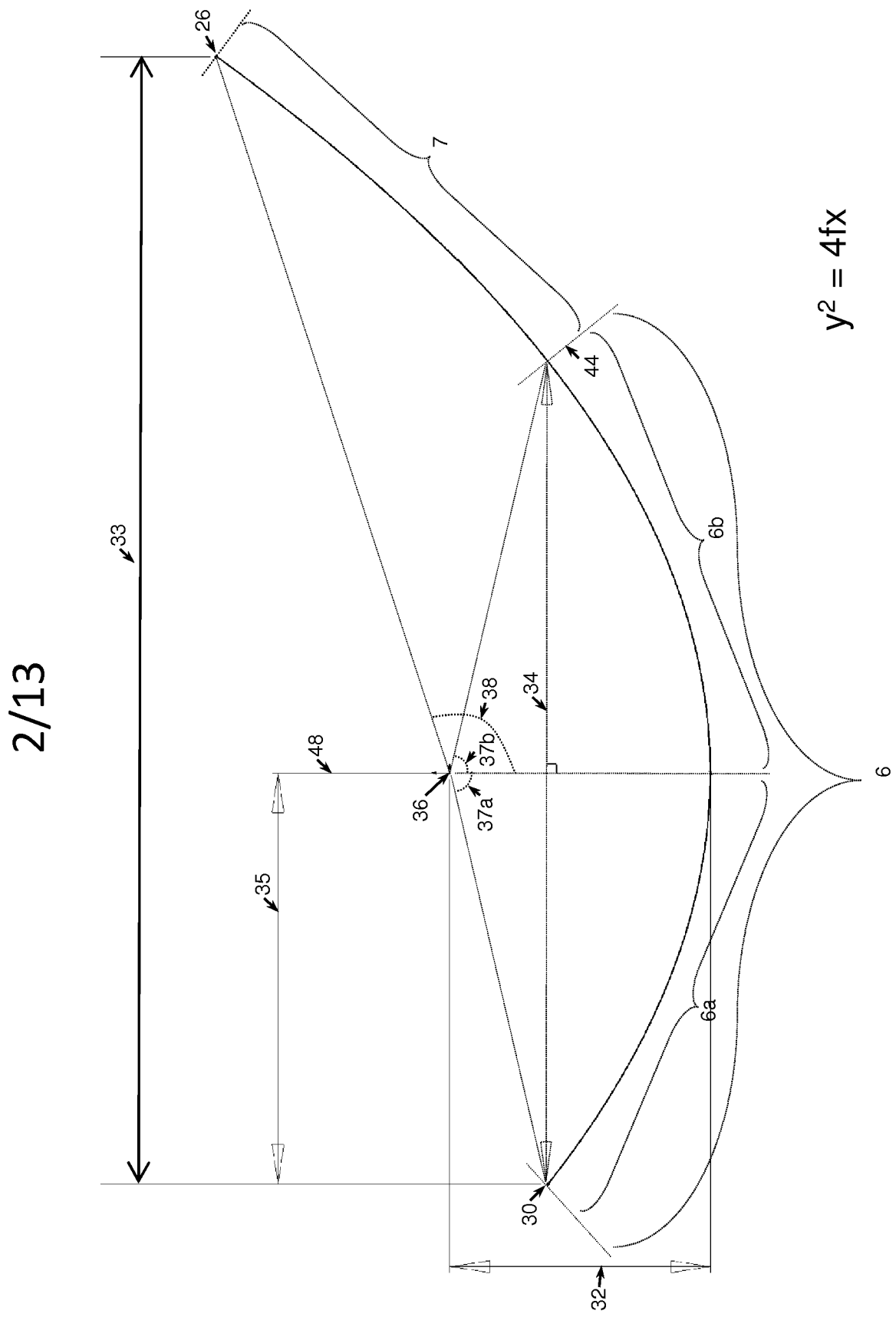
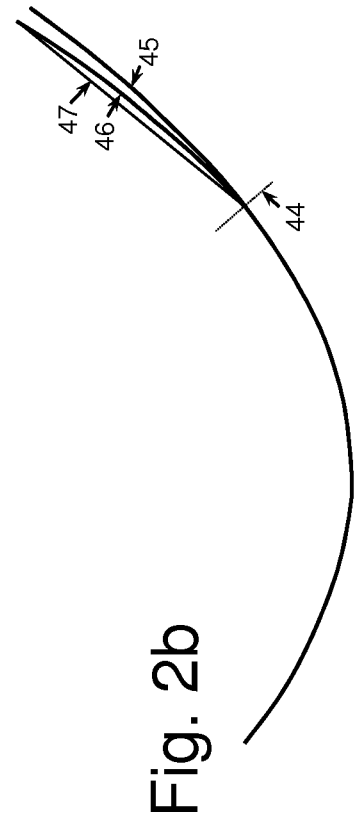
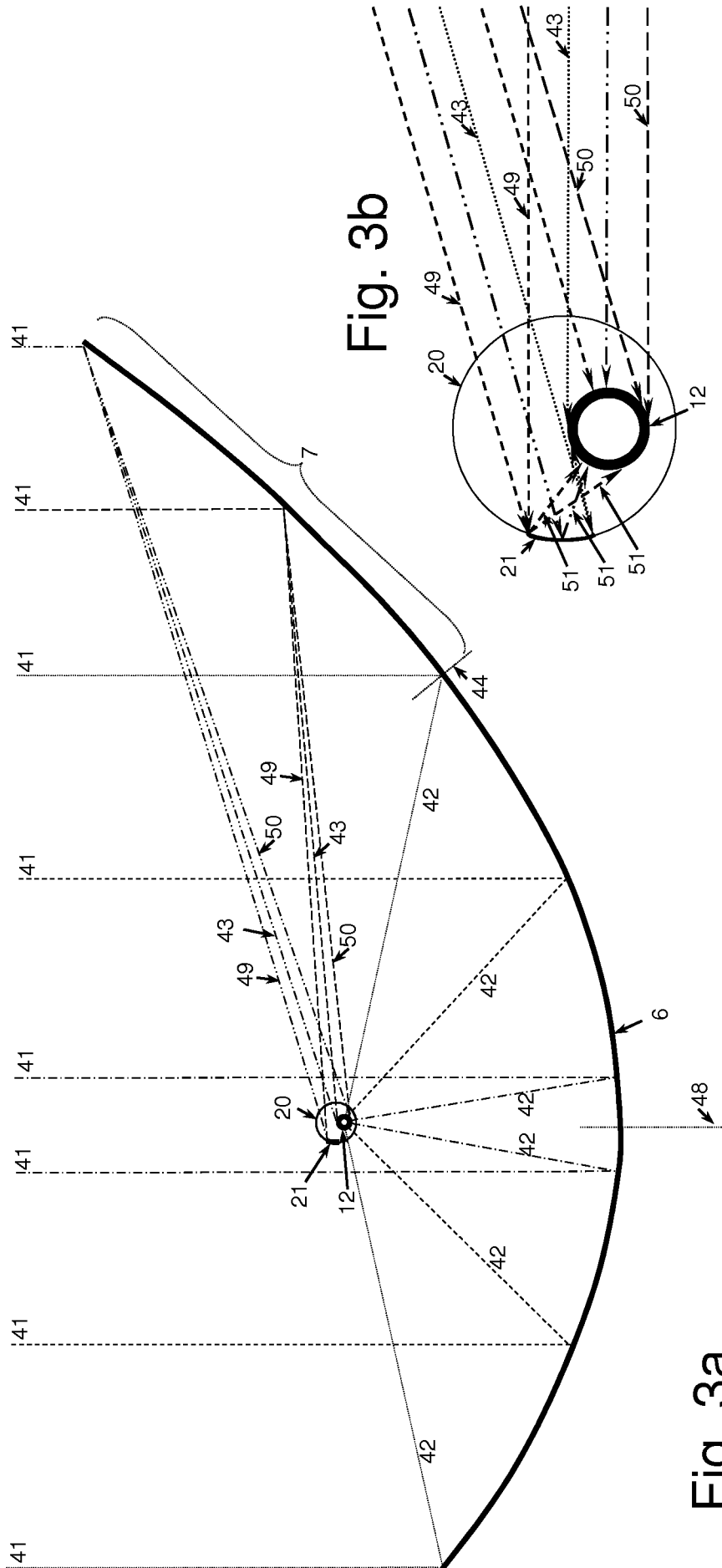


Fig. 2a



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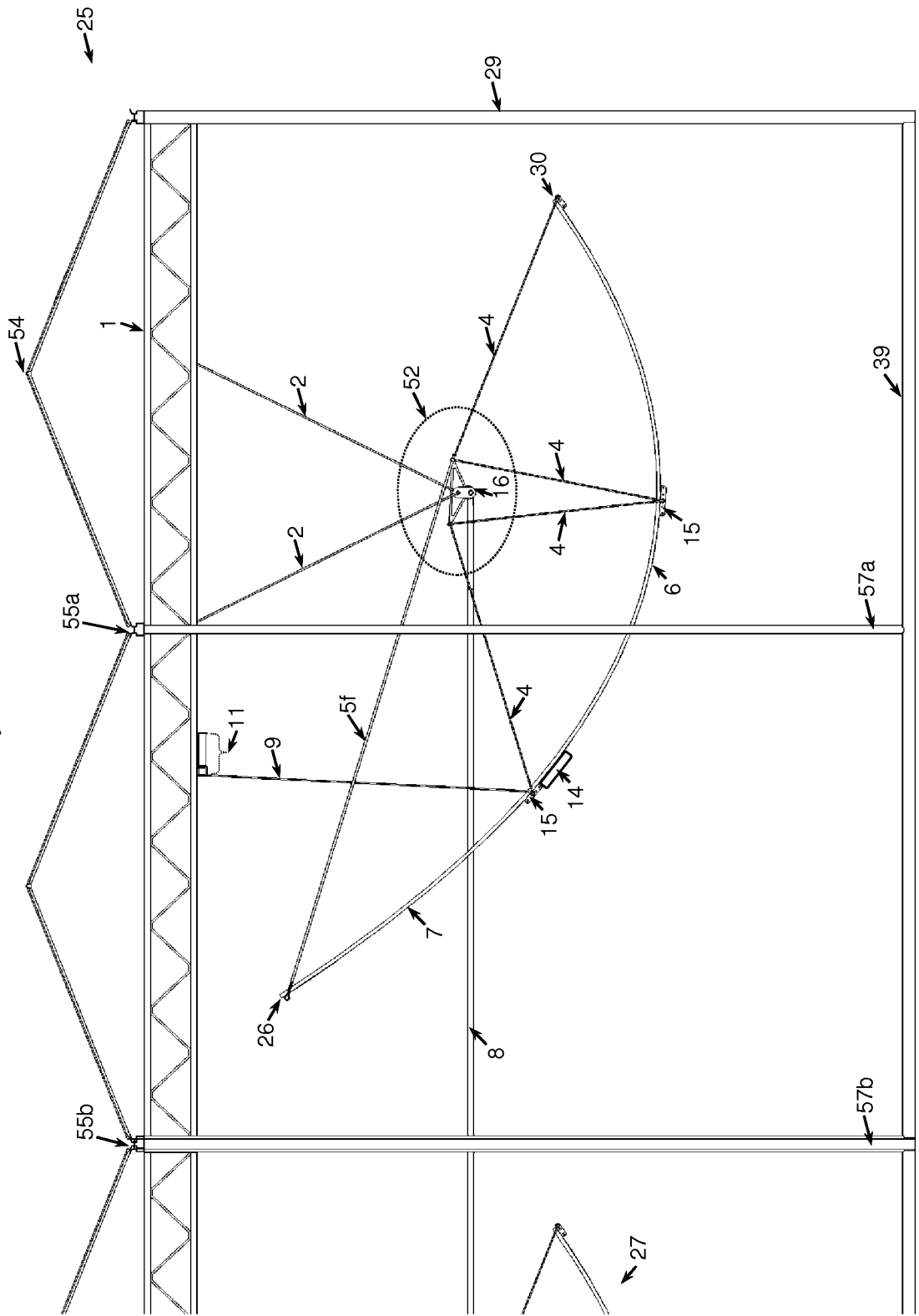


Fig. 4a

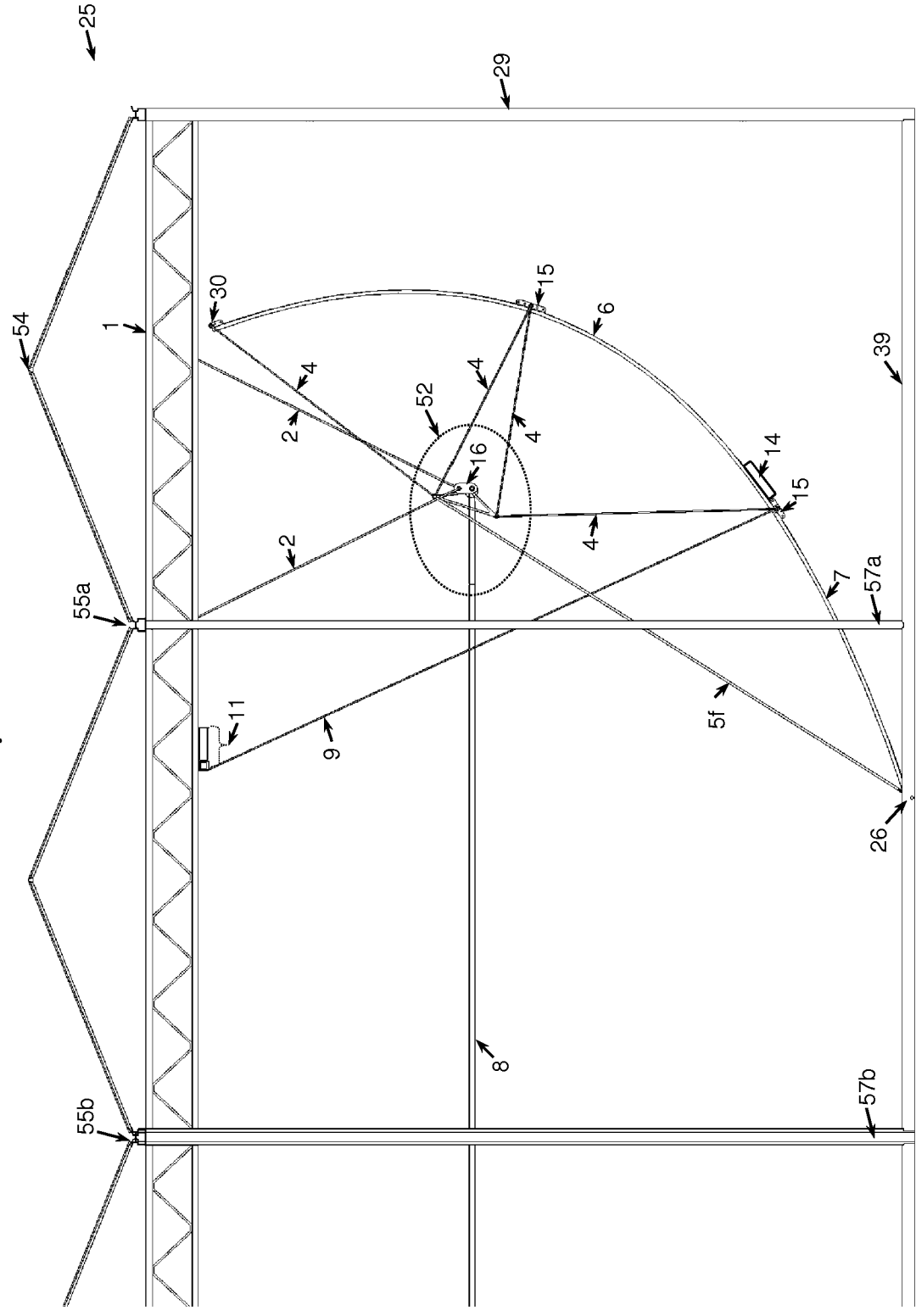


Fig. 4b

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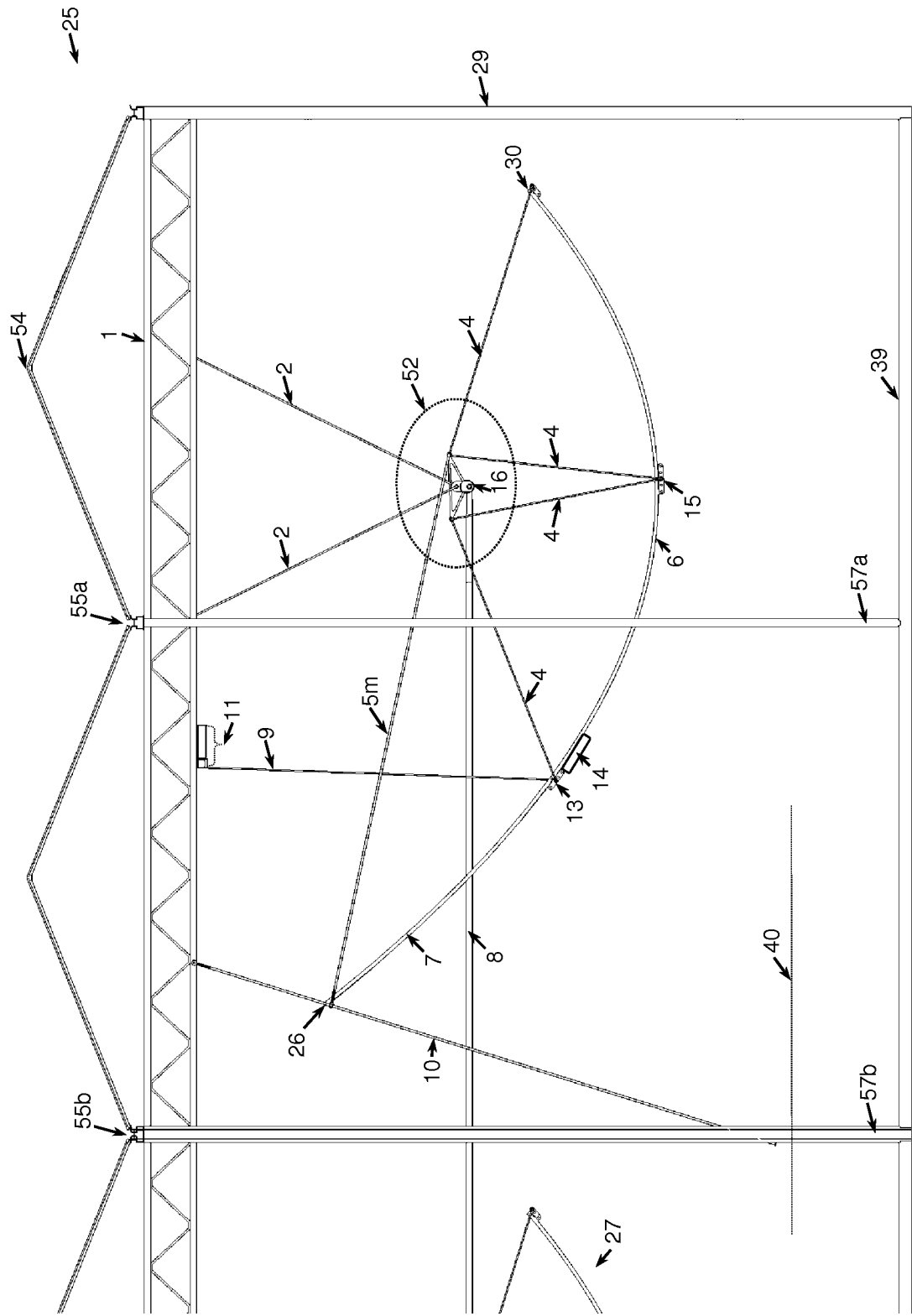


Fig. 5a

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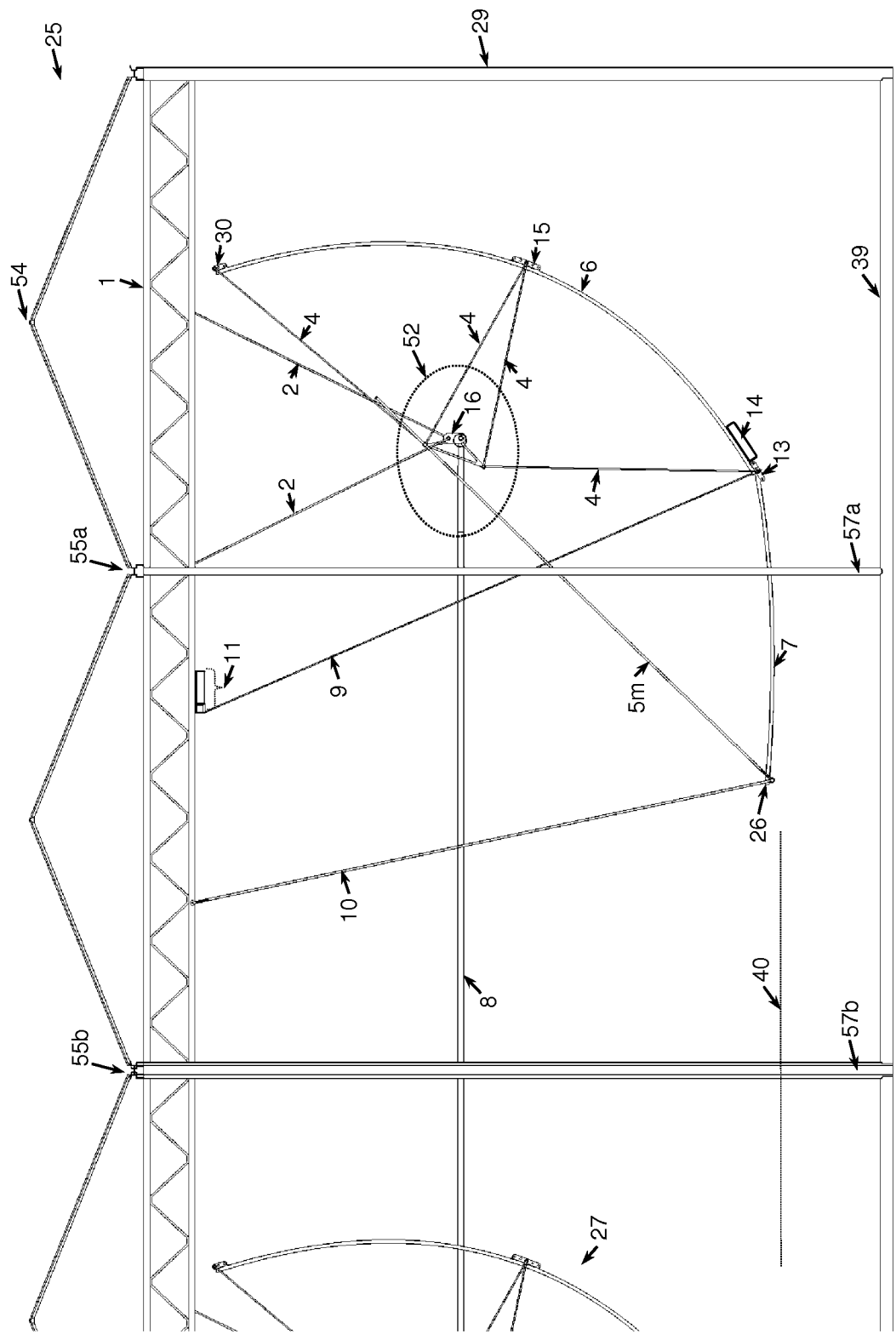


Fig. 5b

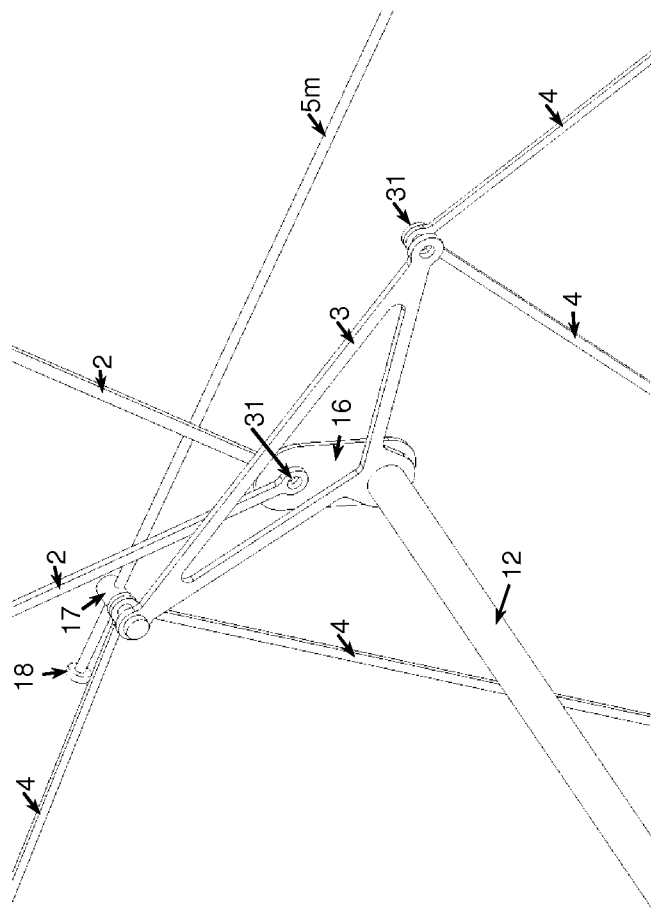


Fig. 6a

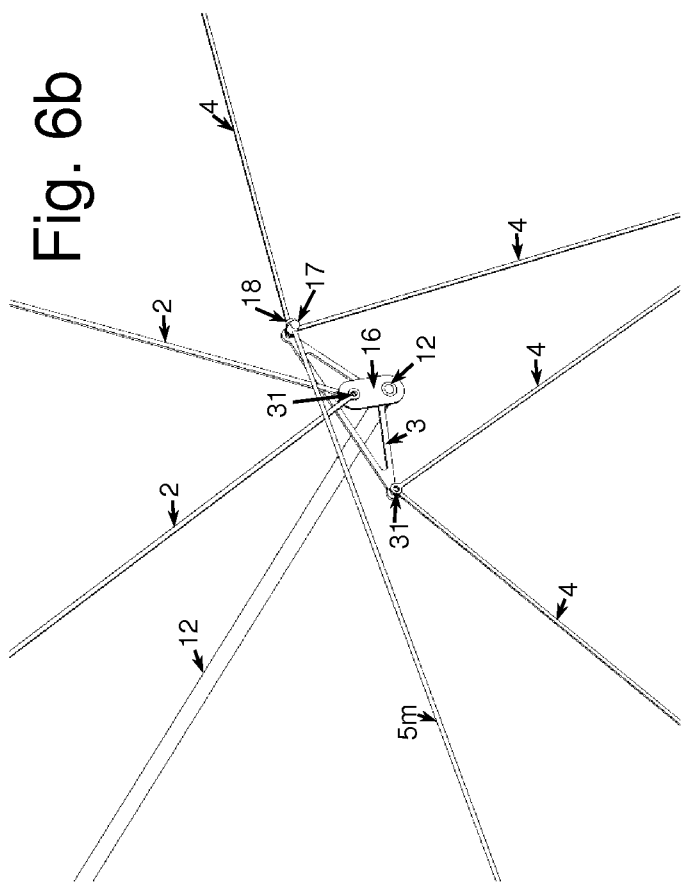


Fig. 6b

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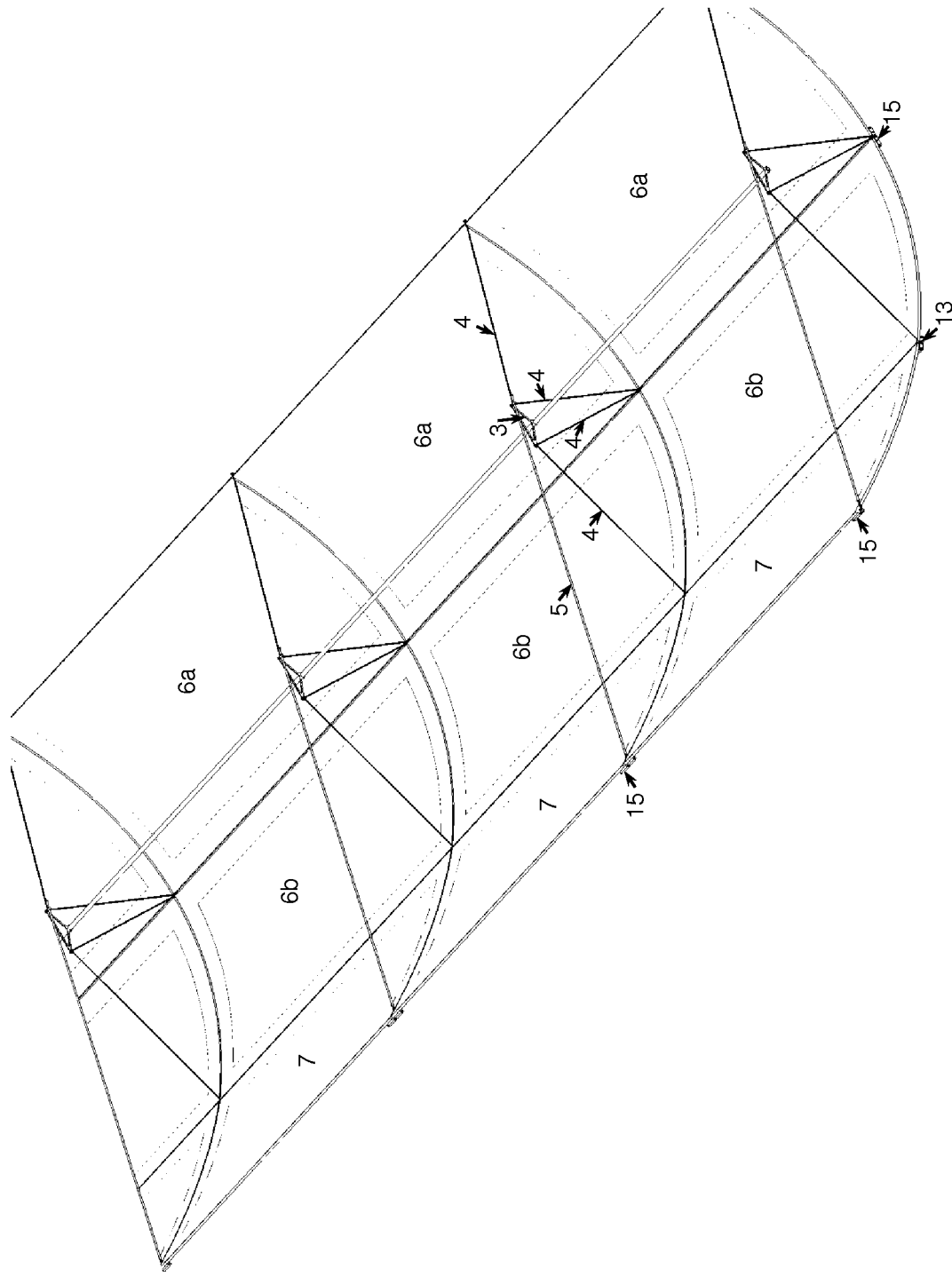


Fig. 7

Fig. 8b

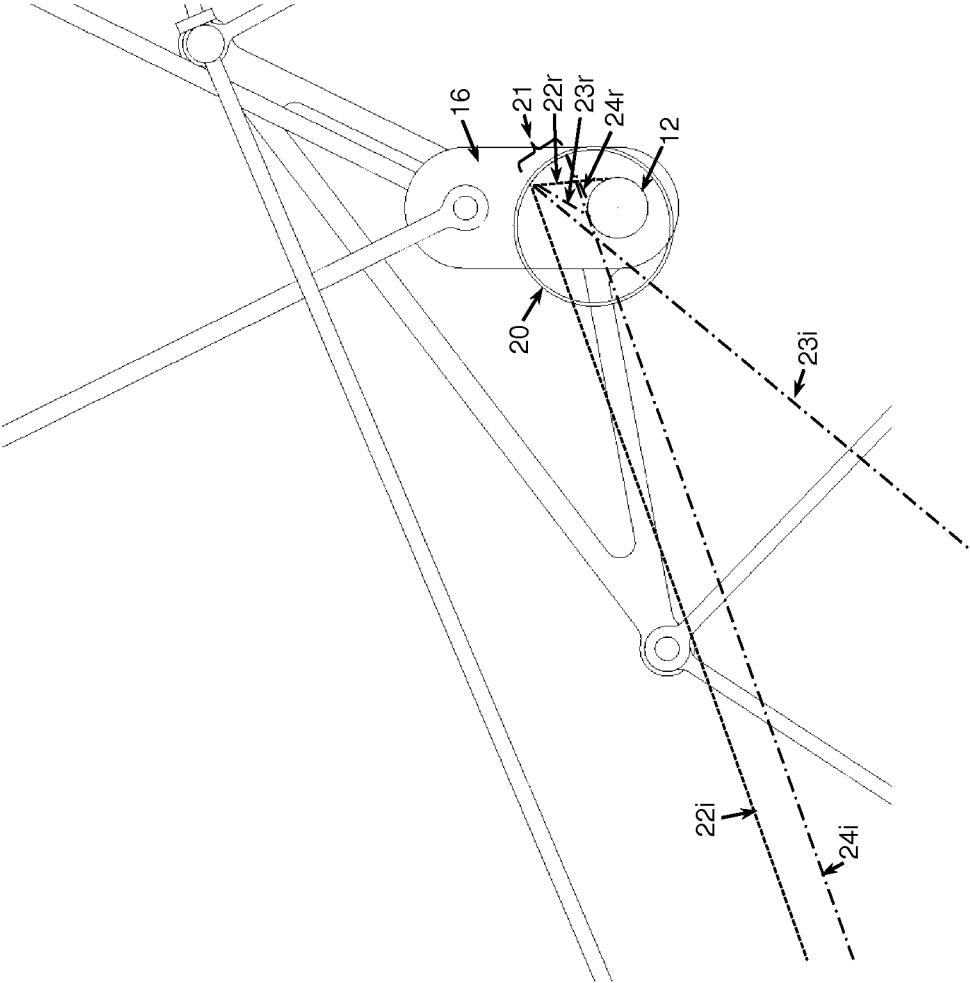
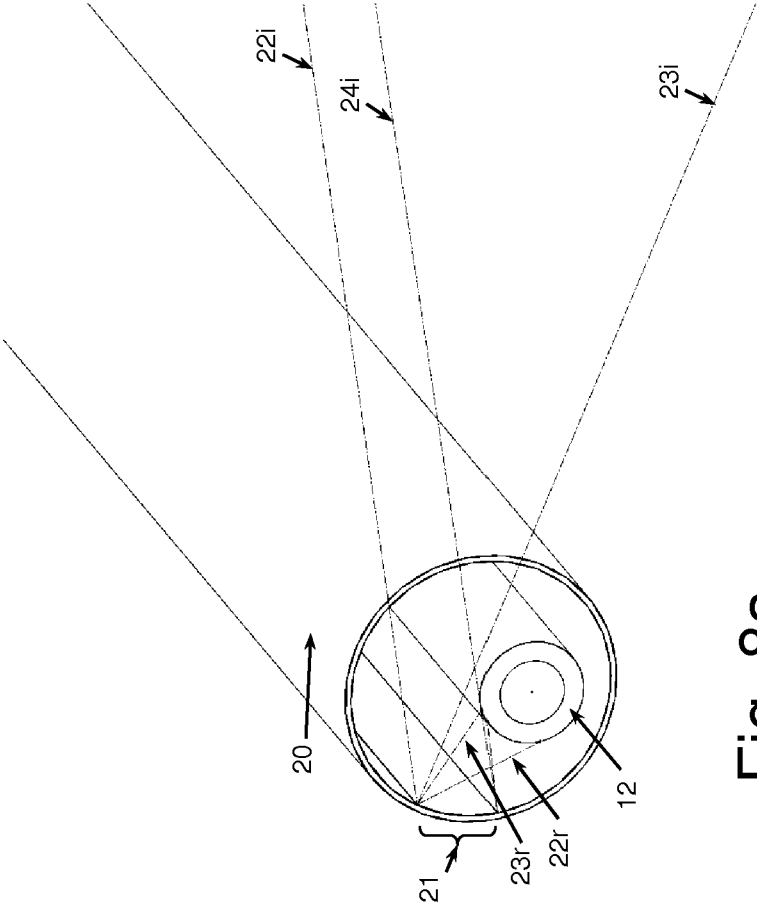


Fig. 8a



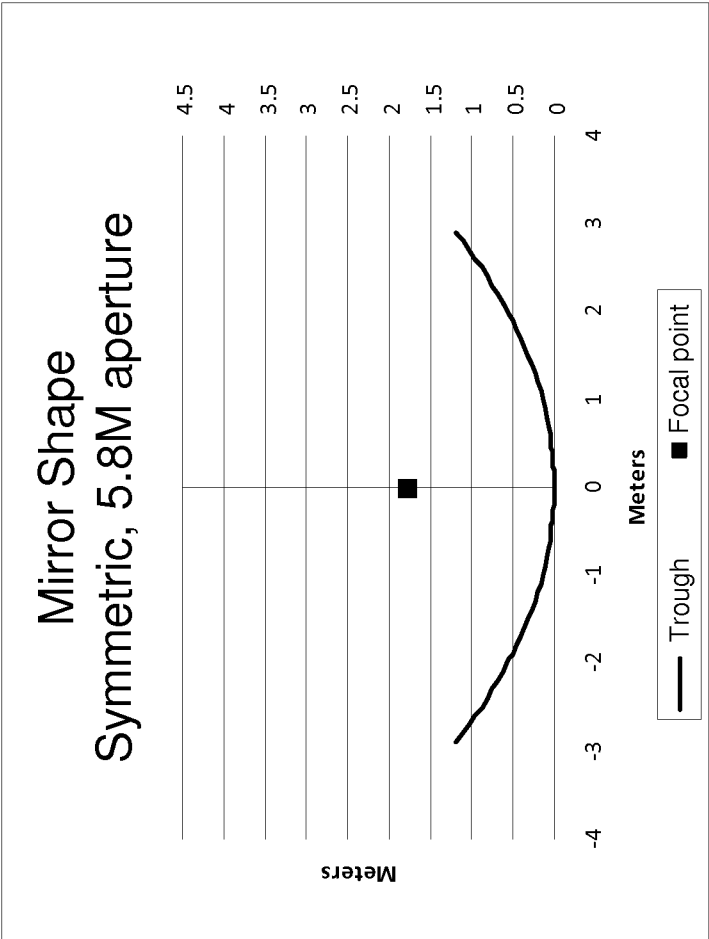


Fig. 9a

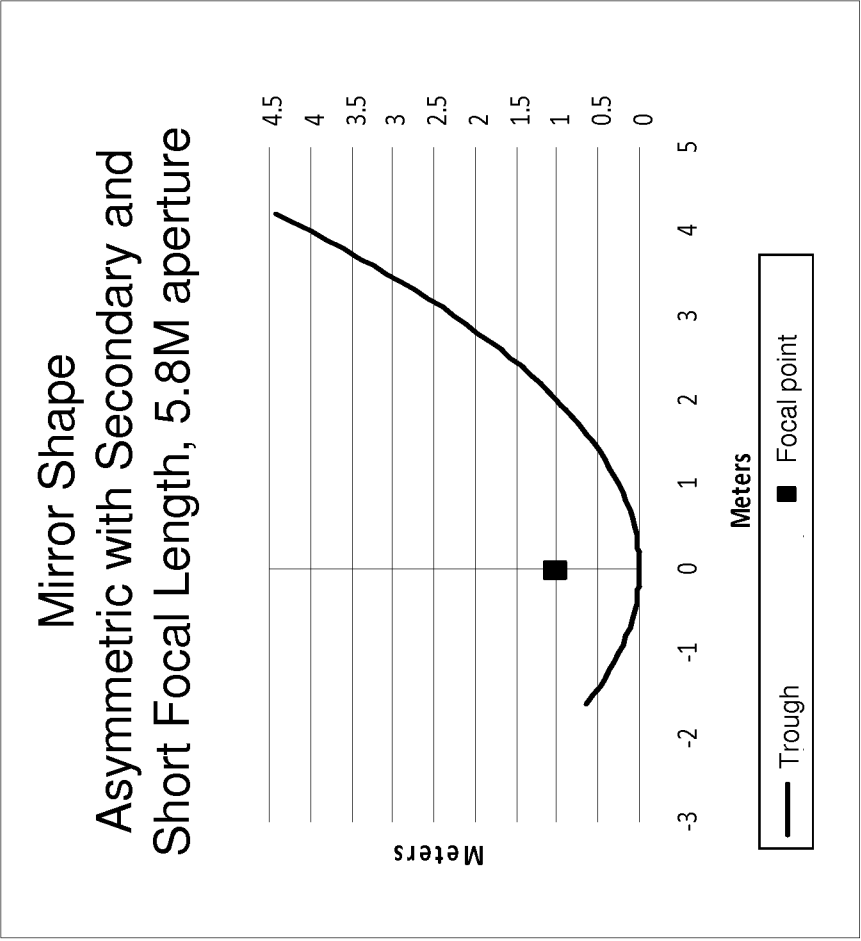


Fig. 9b

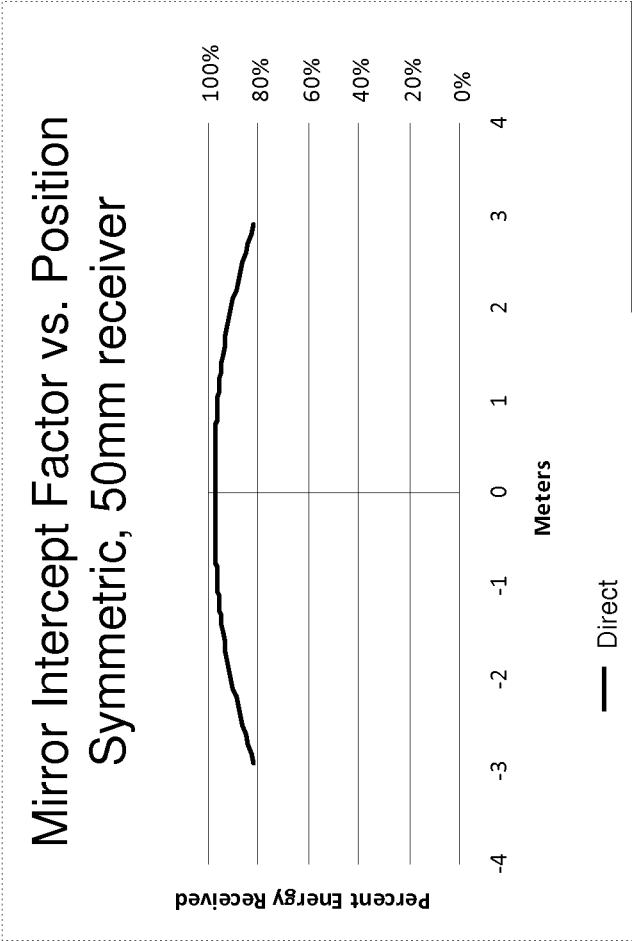


Fig. 10a

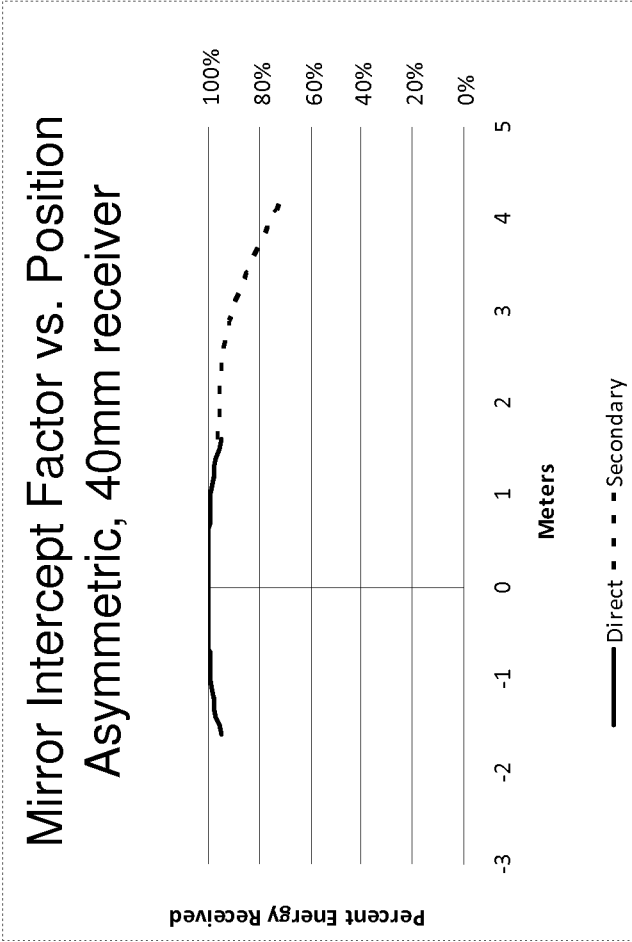


Fig. 10b

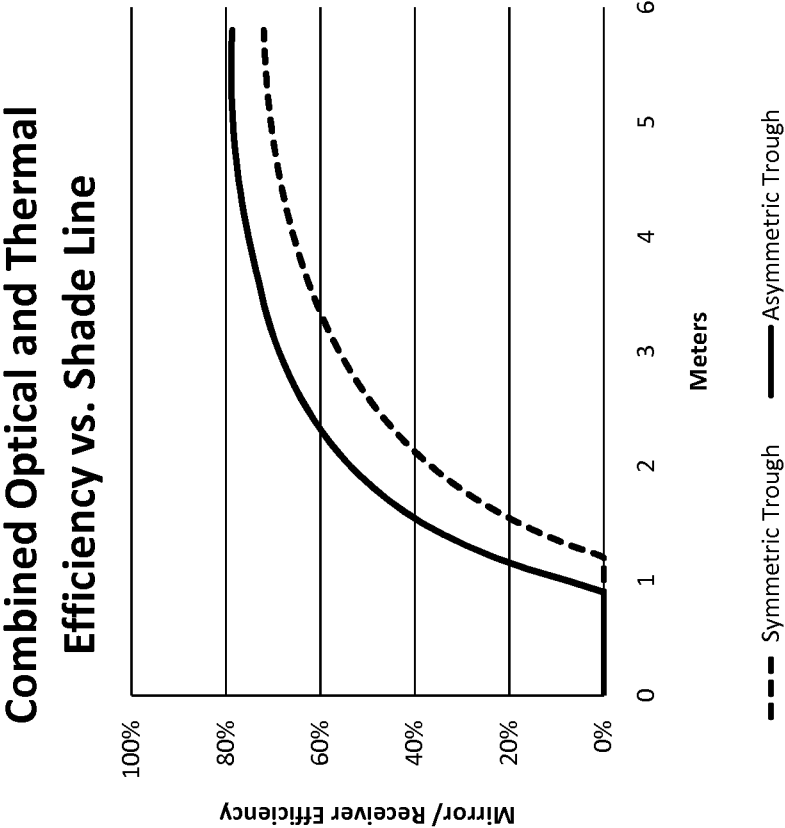


Fig. 11a

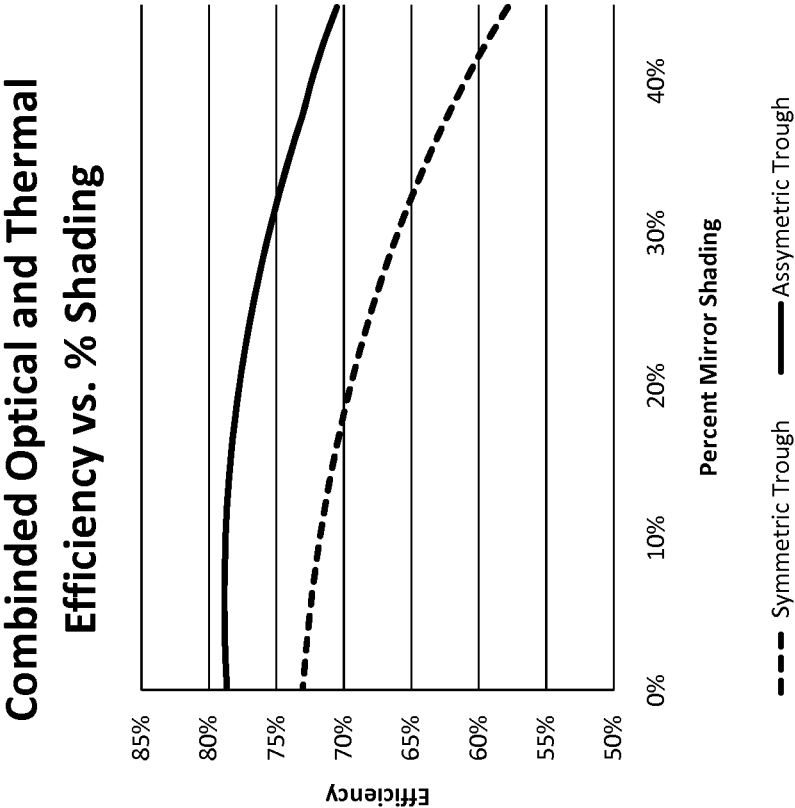


Fig. 11b