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(54) **COLLECTING SOLAR RADIATION USING FRESNEL SHIFTING**

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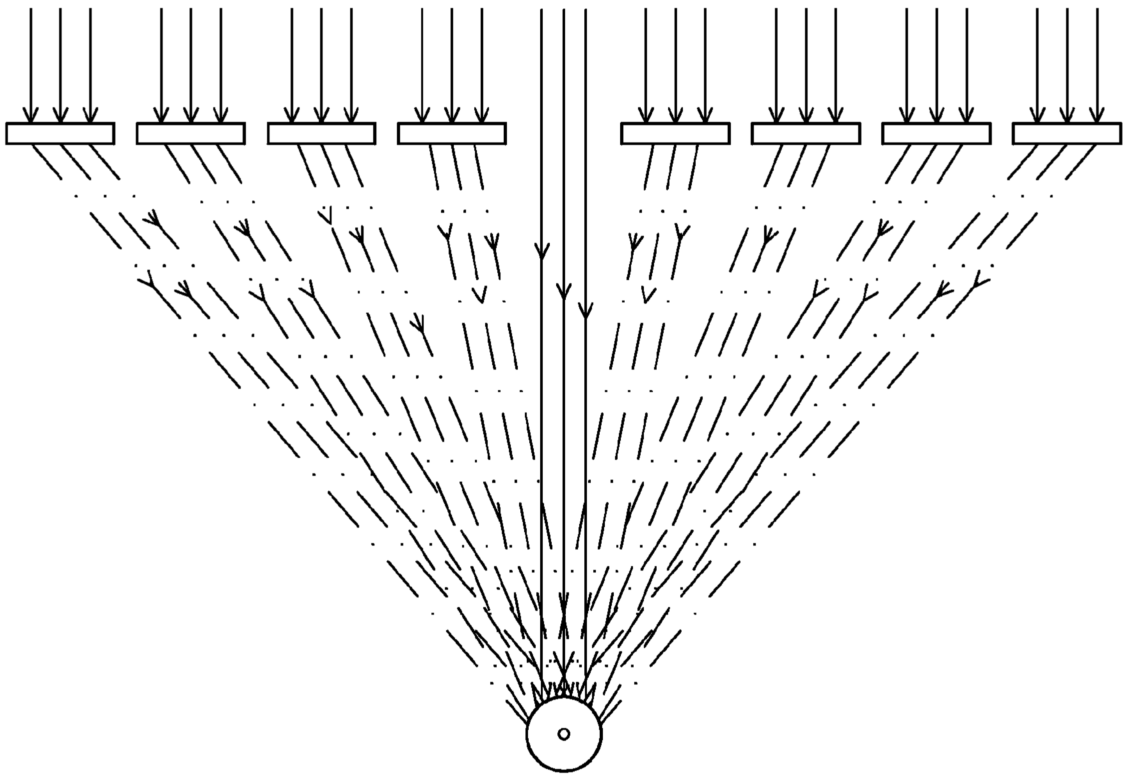
(57) **ABSTRACT**

Solar energy is concentrated on a target by at least one group of Fresnel light-shifting devices.



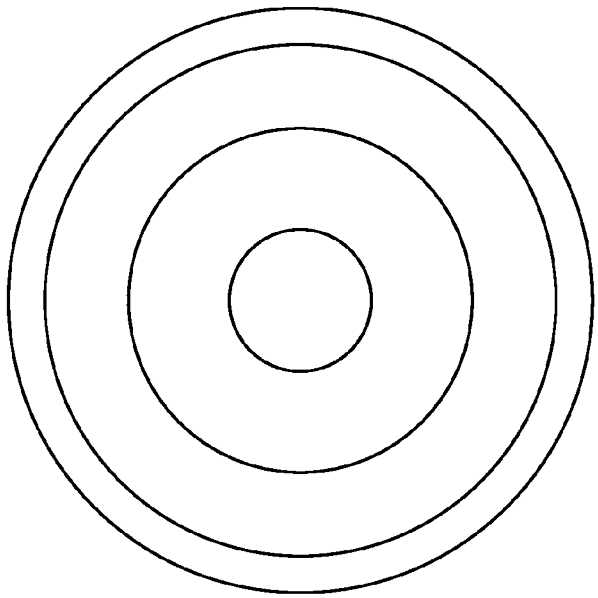


Fig. 1a
(PRIOR ART)

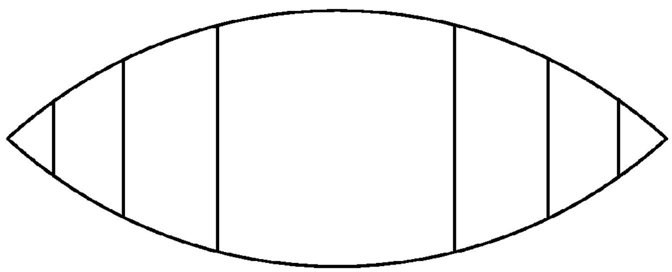


Fig. 1b
(PRIOR ART)

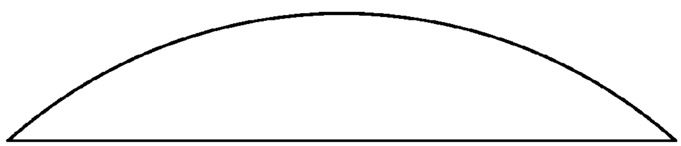


Fig. 1c
(PRIOR ART)

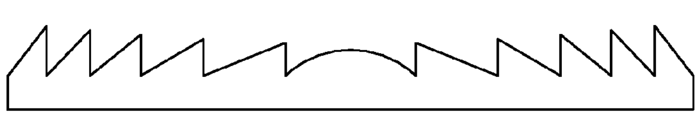


Fig. 1d
(PRIOR ART)

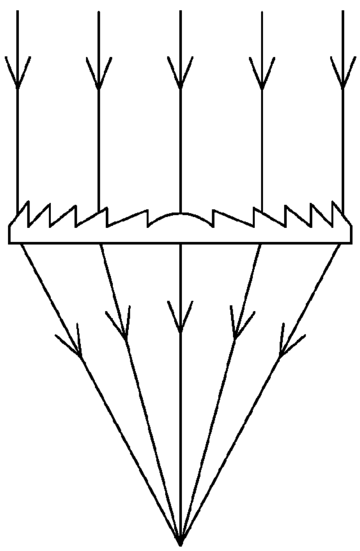


Fig. 1e
(PRIOR ART)

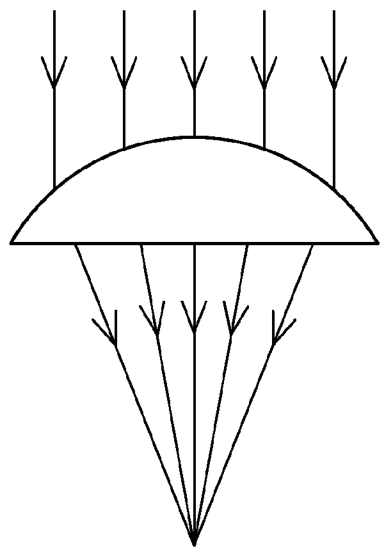


Fig. 1f
(PRIOR ART)

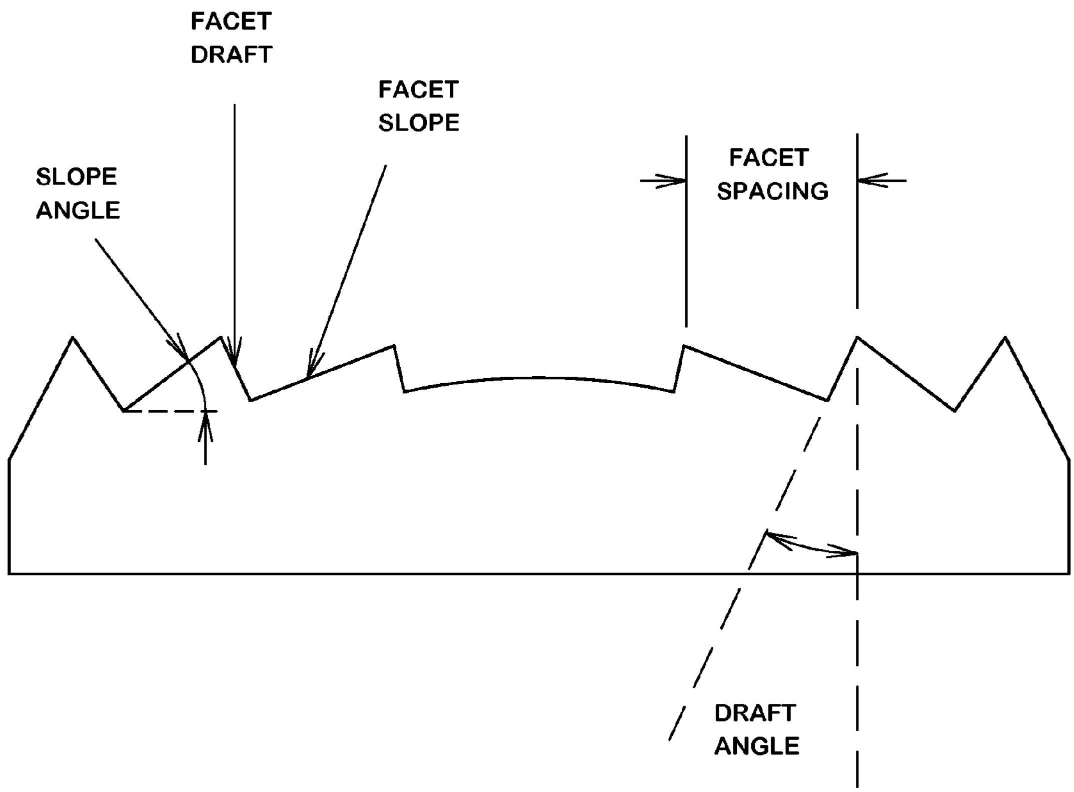


Fig. 2a
(PRIOR ART)

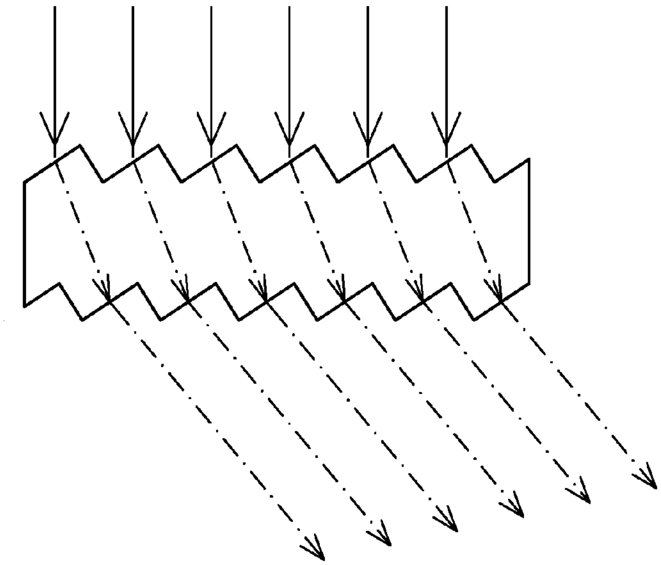
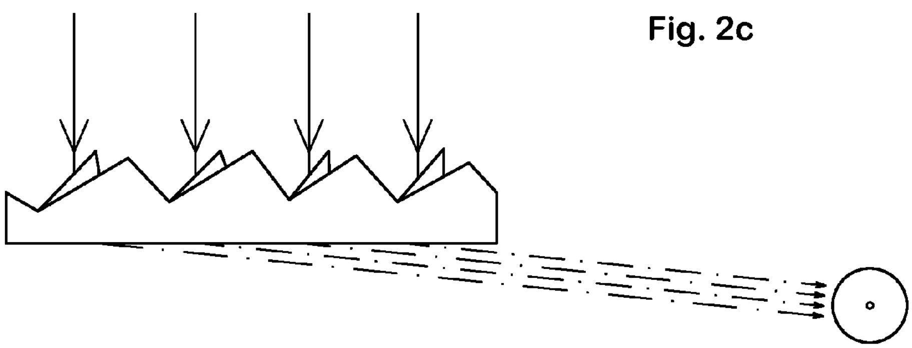


Fig. 2b

Fig. 2c



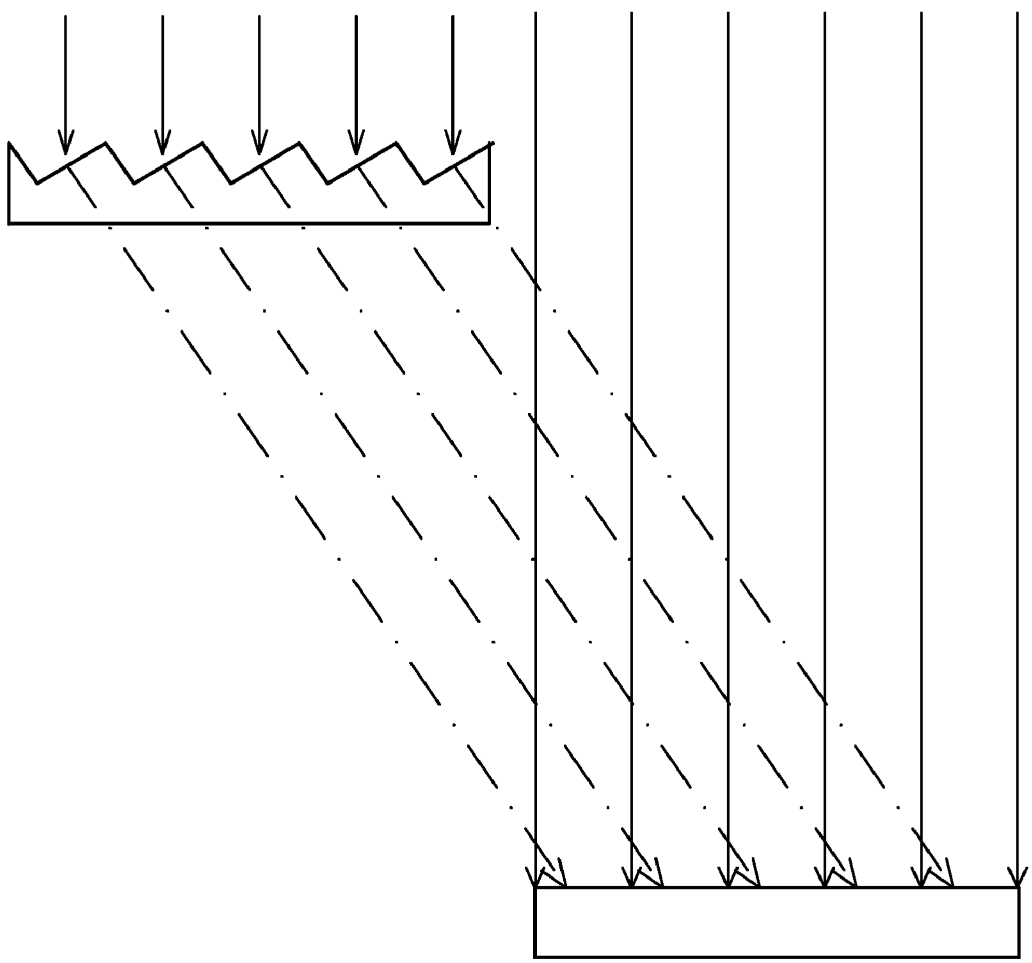


Fig. 3

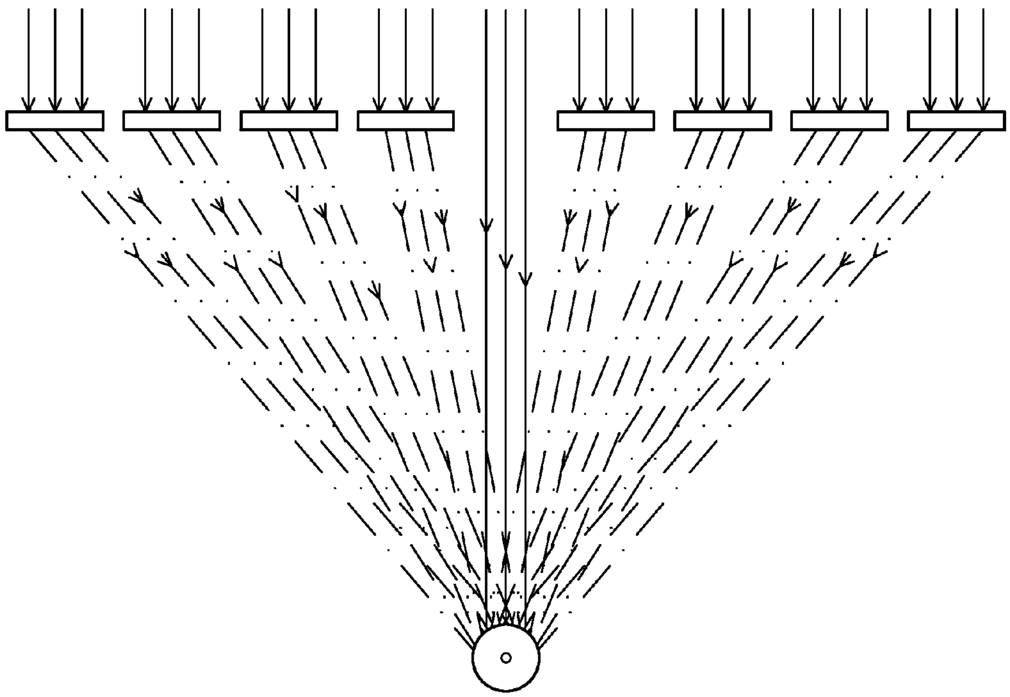


Fig. 4

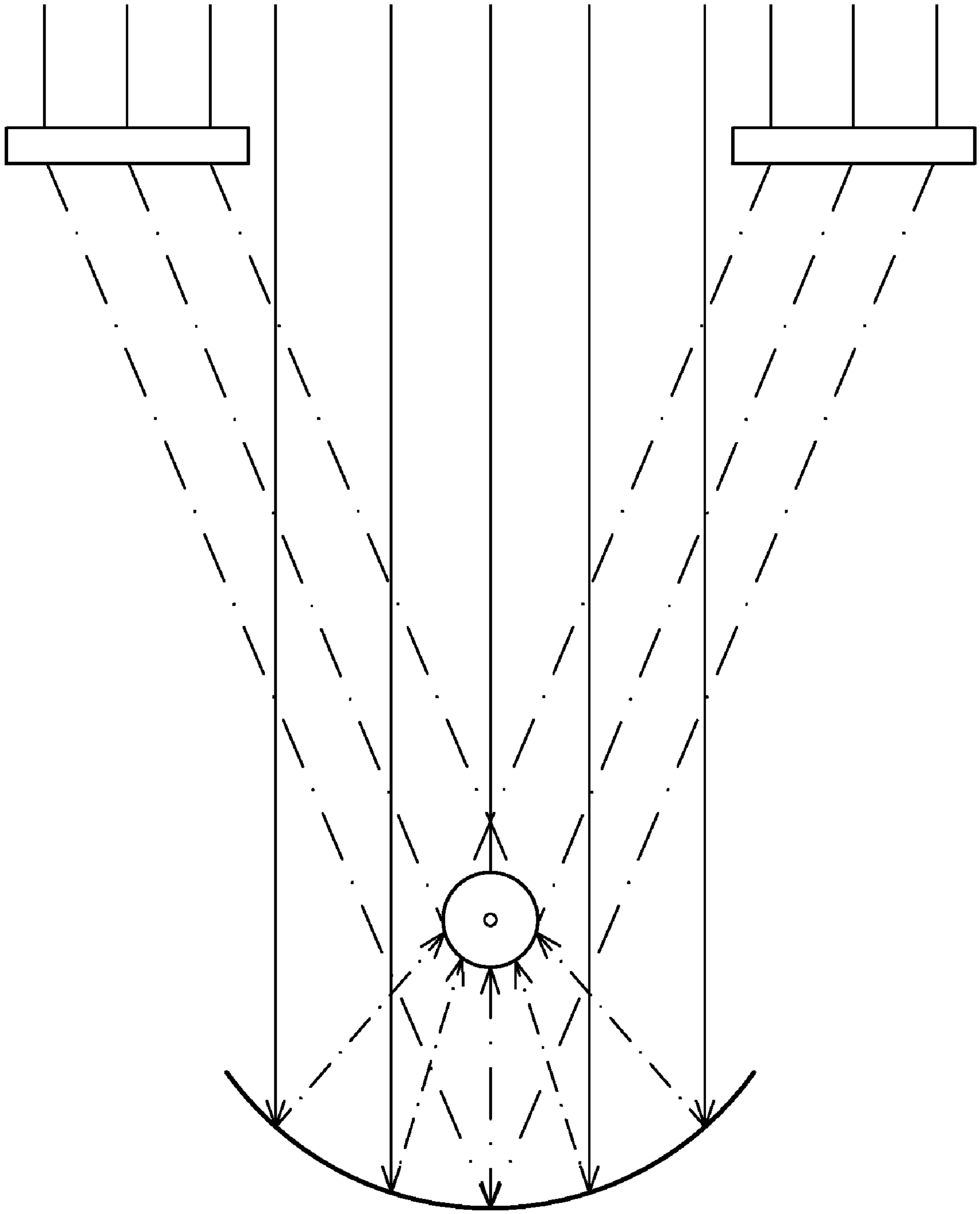


Fig. 5

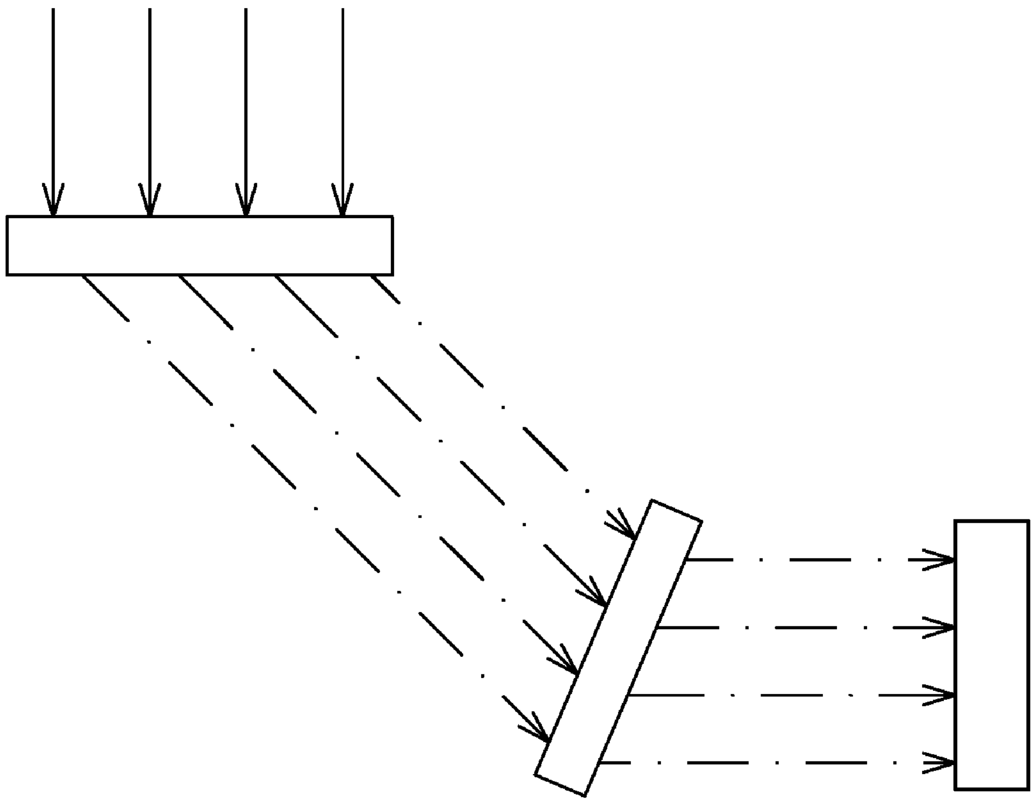


Fig. 6

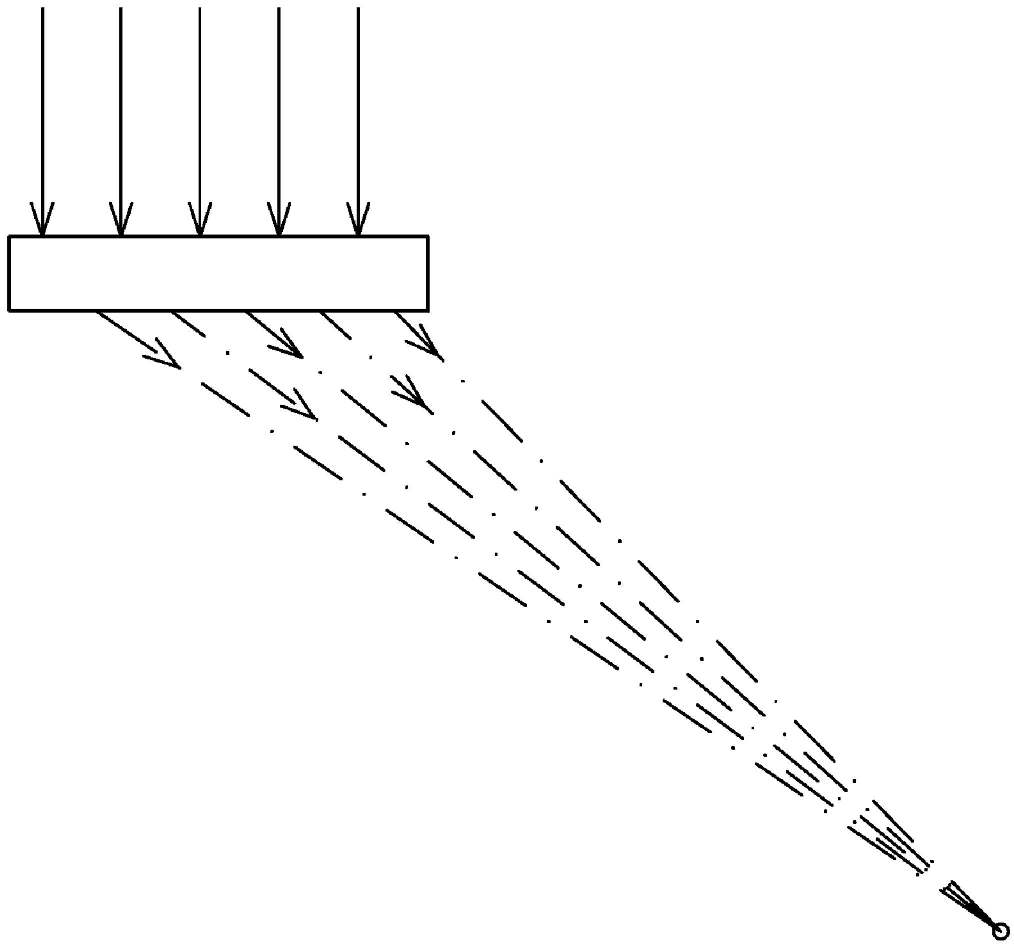


Fig. 7

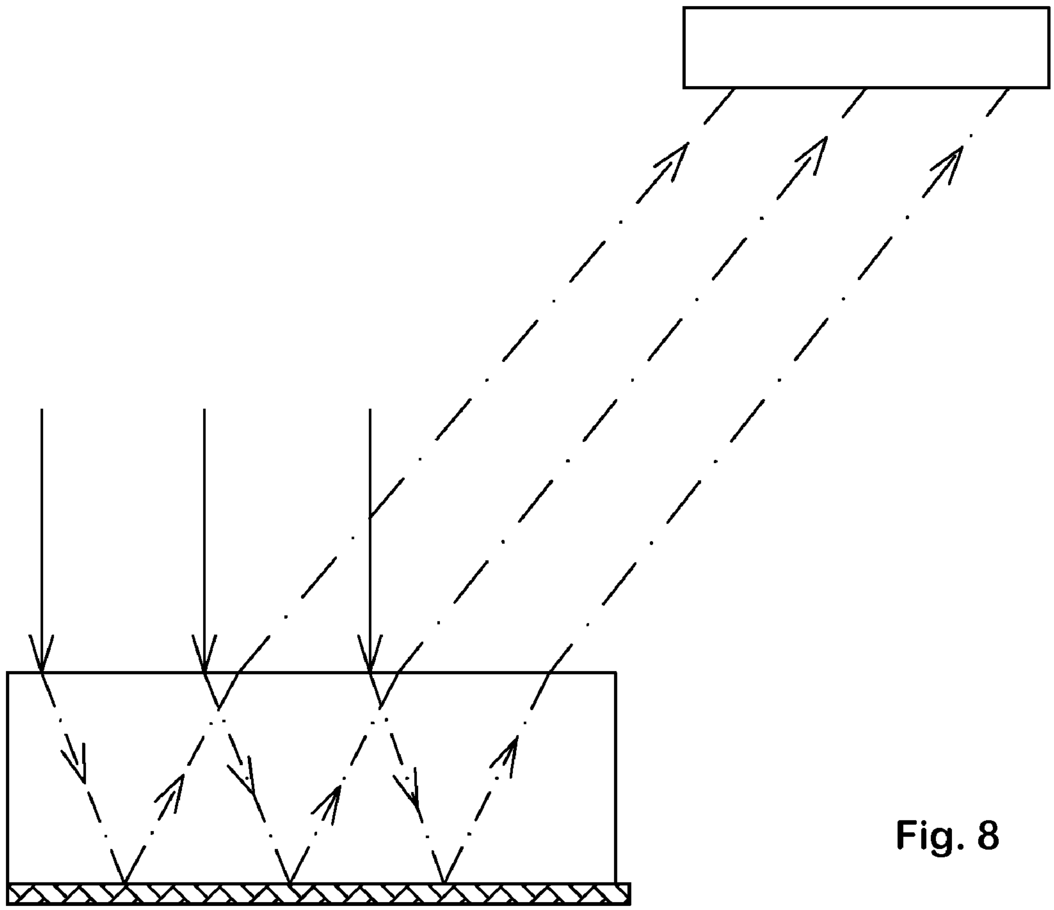


Fig. 8

COLLECTING SOLAR RADIATION USING FRESNEL SHIFTING

BACKGROUND

[0001] Using solar radiation as an efficient energy resource for photovoltaics, heating, lighting applications and the like often requires using the solar radiation in concentrated form. The present state-of-the-art is to concentrate solar radiation mainly by using focusing technology to concentrate the solar radiation prior to use. Focusing is typically accomplished using light transmission lenses including convex lenses and Fresnel lenses, by reflective lenses such as various reflective parabolic structures, or by reflecting solar radiation onto the target using banks of small mirrors. The mirror-based technologies are difficult to manufacture and maintain, while the focusing technologies are limited mainly by constraints of focal lengths.

SUMMARY OF THE INVENTION

[0002] An object of this invention is to enable inexpensive manufacture of devices to effectively concentrate solar radiation.

[0003] Another object is to provide devices that are also more flexible in application than focusing devices.

[0004] These and other objects are realized using the present invention, which is based upon using groups of Fresnel grooves designed to shift solar radiation collected from large areas onto the much smaller solar radiation receptors used to convert the solar radiation into more useful forms such as electricity, heat, and more concentrated light for illumination. By using shifting, most of the limitations of lenses and focusing can be overcome.

[0005] This invention uses a family of Fresnel light shifting constructs based upon groups of Fresnel grooves to shift solar radiation onto solar energy receptors or devices. Using groups of shifting grooves enables solar radiation impacting large areas to be shifted onto the small areas of solar energy devices, effectively collecting or concentrating the solar radiation at the targeted site.

[0006] This shifting method effectively concentrates solar radiation without the stringent limitations imposed by the various focusing methods used as the current convention of the art.

[0007] Freeing the design and applications of Fresnel technology from the constraints imposed by focusing, i.e. freedom from the theoretical and practical limits of traditional lenses, the effective concentration of solar radiation can be greatly facilitated in a cost effective manner. Using the designed Fresnel shifting groups described below enables projecting shifted solar radiation to a common area. Indeed, for some arrangements, the positioning of the solar radiation shifting grooves is effectively independent of the distance between the solar radiation shifting grooves and the targeted solar energy device. The principles of Fresnel shifting as described herein enable collecting solar radiation efficiently and in amounts related to the need. The solar radiation collected by shifting can be directed onto any type of solar energy receptor including non-limiting examples such as photovoltaics, heat collectors including fluid filled pipes, cooking containers, or light tubes or fiber optic cables for transferring light into a structure.

[0008] The manufacture of the shifting devices is also relatively simple in comparison to most types of lenses and other devices used to concentrate solar radiation. Because of the flexibility and simplified design, along with lighter weight, esthetics, varied geometrical options and diversity in locations, shifting applications are more cost effective and relevant to many applications, and often useful even where focusing technologies would be problematic or impossible.

[0009] Because the science of these shifting constructs or devices is based principally upon the historical teachings attributed to Fresnel, as part of the background to understanding this invention some salient features of Fresnel lenses are shown in FIGS. **1** and **2**.

[0010] Lenses, including reflective lenses such as parabolas, transparent convex lenses, and flat Fresnel lenses are commonly used to concentrate or focus light for applications to solar energy, as well as to focus light for use magnification, and other forms of imaging. Lens focusing properties, based upon the contour of the refracting surface of a convex lens, have been known for centuries. According to the principles of the curved lens surface, the curve is relatively flat at the center of the lens surface, gradually increasing in bending of the curved surface until near the edges of the lens circumference, the curve of the lens becomes quite steep, as diagramed in FIG. **1**.

[0011] FIG. **1.1** shows a plano-convex form of such a typical lens. This type of lens led to the understanding that most of the lens material could be ground out to form essentially a step-surface lens, relatively flat, that could mimic the function of the original plano-convex lens. Fresnel recognized that each groove of the stepped lens should represent a corresponding curve of the aspheric surface at that point or line of the original lens, and that the spacing of the circular patterns of the steps should be coordinated with the extent of the curvature of the traditional lens model such that the spacing between the different circles of steps should decreases proportionally to the distance of the step from the center. It is important to keep in mind that Fresnel grooves are designed to mimic the curved surface of the lens. This innovation of Fresnel greatly improved the functioning of the stepped type lenses, and for some applications made the Fresnel-type flat lenses competitive with the convex lenses. A diagram of a Fresnel lens is provided as FIG. **2**, along with two less common examples.

[0012] Fresnel lenses in varying formats are used in a variety of ways, especially for magnification, in addition to numerous applications to focus light as a mechanism to concentrate solar radiation. Because of lens physics and practical limits of the refractive index of useful substrates etched with the Fresnel grooves to construct Fresnel lens, useful sizes of Fresnel lenses seem typically limited to approximately 12 to 14 inches in diameter. Fresnel lenses are also known to be very effective at focusing, forming precise focal points or lines of highly concentrated solar radiation. This is true because each arrangement or line of Fresnel grooves is designed to mimic a specific part of the curve on a convex lens, effectively focusing the light as would that part of the curve on the lens, (See FIG. **1**). Collectively the Fresnel grooves form a fine point or line of highly concentrated solar radiation. The heat generated from this concentration is in the form as "hot spots," creating limitations in some desired applications wherein the intensely concentrated energy would damage the target, such as a photovoltaic device, further restricting the applications of Fresnel lenses with respect to solar energy.

[0013] The principle of this invention is to forego the lens concept and instead to use Fresnel grooves in sets or groups to essentially shift solar radiation onto solar energy targets such as photovoltaic or heat, or other receptors. Because groups of functionally similar or identical Fresnel grooves cannot, by definition, mimic the curve of a lens, such groups can not form such extreme hot spots and can be designed so that the energy distribution across the surface of a solar radiation receptor is uniform in intensity. Depending upon the need, this can be accomplished without focusing as is more preferred, or if desired with various degrees of focusing as preferred for some applications where very dense collections of solar radiation are required as concentrated such as to form a focal line, depending upon the broad embodiment of this invention.

[0014] Through variations of Fresnel shifting, solar radiation can be collected and delivered to a solar radiation target or receptor either evenly across the target in modest amounts or evenly in intense amounts, or as very high intensity hot spots or intense areas linear in character such as a near focal point or line. Because a lens is not used, the size restriction attributed to Fresnel lenses no longer applies, greatly increasing the area and therefore the amount of solar radiation that can collected. This concept also allow different groups or areas of the Fresnel shifting device to be located along the same plane, as is the character of the Fresnel lens, or at different planes enabling additional options for how solar radiation can be collected. Furthermore, and of particular importance, the parallel shift design enables the shifted solar radiation to travel in concert relatively long distances prior to interacting with the solar energy target.

[0015] With this invention, linear devices can be very long (as can be Fresnel lenses) but via this invention can also be very wide, and groups of shifting grooves can be treated independently such that shifting groups can be at different levels if needed, or widely separated yet still transfer solar radiation to the same target. Such is possible by working with groups of Fresnel groves with the same or related solar radiation shifting characteristics within each group rather than with a Fresnel lens or section of a Fresnel lens.

[0016] Although sharp focal areas are possible, they are generally less preferred for home use because they can constitute a fire hazard if improperly used. The flexibility of the Fresnel shifting motif allows incredible variability in design of solar radiation devices to collect solar radiation by shifting the direction of solar radiation wave travel. For example, wherein the shifted waves of solar radiation remain parallel long distances are possible between the location of solar radiation collecting devices and the solar radiation targets, therefore high placement of the Fresnel shifting grooves is feasible. Examples of placement could include off the edges of builds or on other available structures such as supports for wind turbines where the necessary electric grid is in place. Cogeneration of electricity via solar and wind using established fields of wind generators is cost effective because some of the structural support needed for solar radiation collection, and access to an electric grid to transport the generated electricity are already in place. High placement of separate groups of shifting grooves would likely limit the collector geometry to rectangles, the orientation east-to-west, and the solar radiation target to be long such as a heat pipe to account for a moving area of solar radiation concentration. Other arrangements, including circular or even branching such as peddles of a daisy are possible and can result in concentration of large amounts of solar radiation within a small area. This freedom of design is very important to promote applications both for improving energy efficiencies in "developed" countries as well as in "developing" countries where even small improvements such as replacing much of the wood used as fuel to providing safe drinking water, to even inexpensive ways to generate at least modest amounts of electricity can have a great impact in the quality of life for many people.

[0017] By using groups of functionally related Fresnel groves, the limits imposed by the lens equations, and structural limits in lens design are no longer valid, liberating the applications of Fresnel to solar radiation, based principally upon solar radiation shifting groups of Fresnel grooves rather than the traditional lens approach. For most, but not all, applications, the solar radiation shifting grooves are arranged in groups such that the diameter and length of each Fresnel-based shifting group, are approximately the same as the solar energy target. Where the direction of light propagation is extensively altered, where the angle of shifts are very sharp, the diameter of the shifting groups can be larger than the diameter of the target yet all the shifted waves can still contact the target. Fortunately, Fresnel groves, especially in linear arrays are relatively easy to produce in sheets of various types of glazing by common methods including but not limited to etching, extrusion, molding, and imprinting. Such materials are also acceptably attractive, relatively easy to clean, and cost effective in comparison to the major competing technologies such as reflective parabolic troughs or banks of mirrors. The Fresnel shifting devices can of course be tilted to remain more perpendicular to the daily path of the sun, or by accepting some reduction in efficiency orientated more east-to-west along the long axis, perhaps changing angle of position to be more perpendicular to the general path as the seasons change, depending upon the latitude. It should be noted that the transparent Fresnel light shifting devices can be made much lighter in weight than many of the other technologies used to collect and concentrate solar radiation. They are less expensive and easier to maintain under most circumstances than other technologies such as reflective parabolas, or banks of mirrors designed to reflect solar radiation onto a target.

DEFINITIONS

[0018] Targeted solar energy receptor or device includes but is not limited to photovoltaic devices such as to generate electricity directly from solar radiation; heat collecting devices such as pipes or tubes containing liquid or gas fluids, heating solid surfaces such as for cooking, cooking pans and pots and the like; light collecting devices such as to transport light into a building via tubes channels or fiber optics.

[0019] Transparent substrate refers to any glazing or other material enabling visible and or UV and or infrared light to pass through.

[0020] Group of Fresnel grooves means three or more grooves of sufficiently similar character with respect to changing the direction of light waves to enable the solar radiation shift of claim one.

[0021] Domain of the solar radiation shifting device or group refers to the area directly below the group or device, in reference to the direction of incoming rays of solar radiation striking perpendicular to said group or device.

[0022] Solar Energy and Solar Radiation for purposes of this invention mean the broad spectrum of solar radiation including UV, visible and infrared radiation.

[0023] Fresnel shifting means changing the direction of radiation as a consequence of passing through glazing containing Fresnel grooves. For this invention the radiation refers to solar radiation and is not intended to refer to light such as coming from a light bulb.

[0024] Fresnel groove and Fresnel facet are interchangeable terms used to describe the alteration in plane of substrate used to change the direction of solar radiation travel.

[0025] A single solar radiation shifting device comprises one or more groups of Fresnel grooves such that the shifted light reaches the common target of the device. Different groups involved in the concentration of light at a common target though perhaps separate and in different locations are functionally and therefore considered part of the same single solar radiation shifting device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] In the accompanying drawings,

[0027] FIGS. **1***a*-**1***f* show different types of conventional optical lenses;

[0028] FIG. **2***a* is cross-sectional view of a Fresnel lens, showing lens design variables;

[0029] FIG. **2***b* is a sectional view of a lift shifting device having Fresnel grooves on both sides;

[0030] FIG. **2***c* is a sectional view having facets which shift light more than once on one surface;

[0031] FIG. **3** is a sectional view showing a group of Fresnel facets shifting sunlight onto a target;

[0032] FIG. **4** is a diagram showing groups of Fresnel devices shifting light onto a common target;

[0033] FIG. **5** is a diagram showing Fresnel shifting devices in combination with a reflector;

[0034] FIG. **6** shows two Fresnel shifting devices in series before a target;

[0035] FIG. **7** shows a Fresnel shifting device having a focal point or focal line outside the domain of the shifting group; and

[0036] FIG. **8** is a sectional view of a Fresnel shifting device above a reflector.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0037] FIGS. **1***a*-**1***f* and **2***a*-**2***c* are included to help explain some of the features of the historical art relevant to understanding this invention. FIGS. **3**-**8** are included as descriptive non-limiting examples of this invention to promote understanding of the invention, and to gain insight into some of the ways this invention can be applied.

[0038] FIGS. **1***a*-**1***f* are included to provide a basic understanding of the concept of Fresnel lenses including how a Fresnel groove, or facet etched into a transparent substrate can result in changing the direction of waves of light. FIGS. **2***a*-**2***c* are a general presentation from the public domain literature on the basic characteristics of Fresnel grooves or facets that can be manipulated to control the extent to which the travel direction of the light waves are modified upon passing through the structure. In addition to the features mentioned, the refractive index of the substrate also significantly contributes to the extent of change in direction. In known applications to solar radiation, these features are mostly used to create lenses to focus the solar radiation onto a target of interest. In contrast, this invention uses the lens principles of Fresnel for non-lens functions, the principle being to shift the direction of light, without forming the focusing patterns of any of the known Fresnel types of lenses. The concept of this invention can be comprehended by understanding FIGS. **3**-**8** as teaching aids representative of non-limiting descriptions of this art.

[0039] In FIG. **3** and in all subsequent figures, unmodified waves of solar radiation are shown using solid black lines, whereas waves modified in direction of travel are depicted using lines composed of dashes and dots. In FIG. **3**, a translucent substrate is etched with a series of uniform Fresnel grooves such that incoming parallel waves of solar radiation impact the shifting device and are shifted to the same extent such that upon exiting the device travel in the shifted direction while maintaining the parallel character. In this manner when the shifted light waves reach the target they are uniform and do not form hot spots on the target as would occur if the light waves had been focused. In this example the same target also receives solar radiation not altered in direction. The combined effect is to add more energy evenly distributed across the target than would otherwise occur. This configuration would be especially useful to increase the amount of light impacting photovoltaic panels to increase the amount of energy that could be produced. With this method, the output of existing photovoltaic panels could be greatly improved. It is far less expensive to produce the transparent Fresnel shifting devices than it is to produce the photovoltaic panels. Depending upon how much additional energy the type of photovoltaic could efficiently utilize, many different shifting groups could be used to collectively shift the total amount of solar radiation desired onto the photovoltaic; for an example of such an arrangement, refer to FIG. **4** and modify by replacing the round target shown with a photovoltaic device of the shape desired.

[0040] FIG. **4** shows one example of how many and different solar energy shifting groups can work in concert to shift large amounts of solar radiation onto a target or solar radiation receptor. Note that this sketch is as a cross-section. The shifting groups could be arranged for example as long parallel rectangles or even circles of groups depending upon the need. Long rectangles of shifting groups might be preferred to heat fluids in pipes or tubes or long photovoltaics, whereas a circular pattern would be effective to impact a small area with lots of solar radiation, for a variety of applications ranging from movement of light such as via a tube or fiber optic cables, to outdoor cooking Heating of tubes or pipes containing fluids is of course important for household space and hot water heating, power to drive steam turbines for electricity and for moving heat into cooking platform to name a few. Of further interest, because the shifted light waves remain parallel, they can travel long distances prior to interacting with the target, enabling large areas of solar radiation to impact relatively small targets for functions where lots of solar energy is required in concentrated form. The shifting groups can be connected in the same plane, as separate in the same plane as drawn, or they can be in different planes from each other enabling a wide variety of designs. The only real requirement is that the shifting groups are coordinated to reach the receptor to fulfill the objectives at hand Freeing the geometry from focusing enables one to take advantage of the local environment depending upon what is available to help support the shifting groups. Shifting the direction of light travel, while maintaining the parallel character of the waves, is also an excellent way to transport energy. Such devices could be placed where there is sunlight, and transport the light to area where it is needed, even if the desired area is otherwise shaded. Shifted solar radiation could also be directed to a solar energy device located on or near the ground from long distances away such as from the edge of a building or other tall structures.

[0041] FIG. **4** also reveals much of the strategy of the invention and stimulates thinking with respect to applications, advantages and limitations of various designs and arrangements of the groups of Fresnel shifting grooves. For example, if the shifting groups are co-joined, the plane of the collector can be kept perpendicular to the incoming parallel rays of solar radiation by rotating the shifting platform in an arc and maintaining the solar radiation target at the center, with or without tilting the receptor. However, co-joining the shifting groups creates the analogy of a lens because a fixed distance is now required between the shifting device and the target, analogous to the focal length of a Fresnel lens. Because this distance is based upon the number of Fresnel shifting grooves per group, there is a great deal of flexibility in the diameter of the shifting device and consequently in the fixed distance between the shifting groups of the solar radiation device and the receptor or target. By descriptive analogy the practical (rather than theoretical) diameter of a point or line of a Fresnel lens could be, as an instructive example, about 0.01 inch which can be achieved with about a twelve inch diameter Fresnel lens. For a non-limiting example of this Fresnel shifting invention, a practical area of solar radiation concentrated on the solar energy target might be two inches for a fluid-filled pipe as the target. Ay analogy of ratio, the 0.01 inch focal diameter is to the two inch concentration area as the twelve inch lens is to diameter X. In this equation X is about a two hundred feet in diameter of the shifting device representing a probable near maximum limit of the possible diameter to form a two inch area of concentrated solar radiation. However, the size of the shifting device to reach this two inch area could also be designed to be much smaller. Of course the focal length of the lens and the concentration distance between the shifting device and the target would also be related by about the same ratio and for a shifting device that large the device would likely have to be about one hundred feet above the solar energy receptor, though by decreasing the size of the shifting device this distance could also be decreased. This example is a bit extreme as the amount of light that could be brought to an area two inches in diameter form a two hundred foot in diameter solar radiation shifting device, assuming nearly one hundred percent efficiency would be about a 14,000 fold concentration. If the shifting groups are separate, the limits in size of the shifting device are effectively restricted only by engineering considerations including support structures and maintaining alignment. Of interest, these two different arrangements of groups of shifting grooves are not mutually exclusive, as the area of a smaller shifting device could be supplemented by other free standing shifting groups shifting additional light either directly onto the target, or onto the fixed shifting device itself.

[0042] FIG. **5** is intended to show that the group shifting technology of this invention can be used to supplement existing technology to improve overall function. There are many reflective parabolic troughs currently in use to concentrate solar radiation such as to heat fluid-filled pipes. By adding shifting groups, the amount of energy received by the collecting pipe can be improved even if many of the shifted light waves miss the collecting pipe. They could then be reflected back onto the target using the existing reflecting parabolic trough.

[0043] FIG. **6** is included to demonstrate that several shifting groups can be used in tandem to shift solar radiation onto a chosen target. The shifting system to direct solar radiation is very flexible in application.

[0044] FIG. **7** is a diagrammatical description that Fresnel grooves can be organized to alter the direction of light to form a focal line outside the domain of the light shifting group. The figure is a cross section of a cluster of light shifting grooves orientated such that light is focused, but unlike a lens, is focused to a line outside the domain of the shifting device, depicted here by the cross section of the line indicated by the common point of intersection. By using many analogous groove clusters in different positions, a large area of solar radiation can be brought to intersect at the same line, enabling extensive amounts of solar radiation to concentrate along the line. This arrangement is not proposed for home use because the amount of energy concentrated could be dangerous, including creating a potential a fire hazard. For comparative descriptions of off axis focusing see Barone, United States Patent Application number 2005004107.

[0045] FIG. **8** illustrates a reflective surface or mirror in combination with shifting of light as shown in FIGS. **3-7**, greatly expanding the applicability and flexibility of this invention. Using a mirror to reflect the shifted solar radiation back through the same shifting group results both in reflection of the light and enables a second passage through the shifting group yielding both the reversal in direction of transmission of the light, and an increase in the angle of the shift. Because of the reversal in direction of travel, and increased angle of the shift, additional amounts of solar radiation could be directed to the solar energy targets synergistically with shifting devices of FIGS. **4-7** by placement of the mirror-backed shifting devices beyond the limits of the primary shifting devices and below the solar radiation target. An all mirror backed system can be used to concentrate solar radiation onto the target located above the shifting grooves adding additional flexibility to applications of the invention.

1-3. (canceled)

4. A method for shifting solar radiation onto a solar energy receptor using a transparent substrate having Fresnel grooves selected from the category consisting of:

at least one group of Fresnel grooves sufficiently identical within the group such that parallel waves of solar radiation are altered in direction of travel to the same extent, as a consequence of passing through that group,

at least one group of Fresnel grooves sufficiently similar within that group such that parallel waves of solar radiation passing through said group remain sufficiently parallel to each other from said group, such that the majority of the solar radiation waves interact with the solar energy receptor,

at least one group of Fresnel grooves each group focusing parallel rays of solar radiation passing through that group to form a focal area outside the domain of the solar radiation shifting group, and

Fresnel grooves focusing parallel rays of solar radiation passing through the grooves such that a focal line is formed line outside the domain of the solar radiation focusing grooves.

5. The method of claim **4** wherein solar radiation passing through the Fresnel substrate is reflected back through the substrate prior to interacting with the solar energy device.

6. A solar energy concentrating apparatus comprising at least one group of Fresnel light-shifting devices.

* * * * *