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(54) **DYNAMIC DISTRIBUTED TOWER RECEIVER SYSTEM FOR COLLECTING, AIMING AND RECEIVING SOLAR RADIATION**

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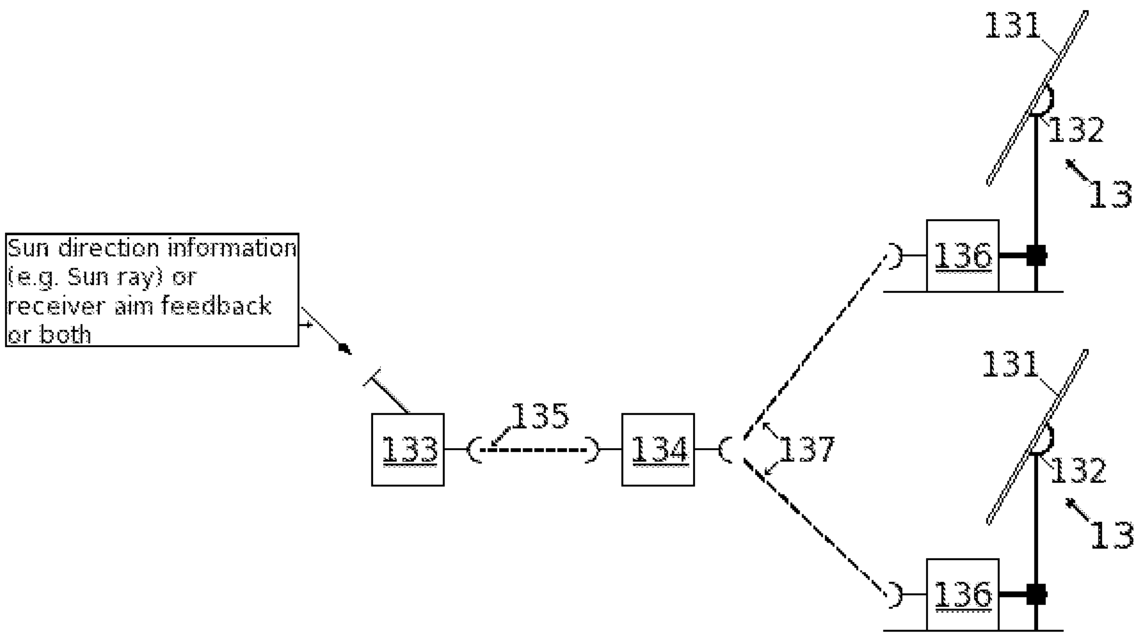
(57) **ABSTRACT**

The invention involves a time dependent method for reducing cosine loss from heliostat fields in receiver system solar power plants with not one but multiple towers and multiple receivers. In this method heliostats change which tower mounted receiver they aim reflected Sun rays through day times to reduce cosine loss. In preferred embodiments a field of heliostats of several tens of acres has many towers and receivers. These systems are called dynamic distributed tower receiver systems (DDTRS).



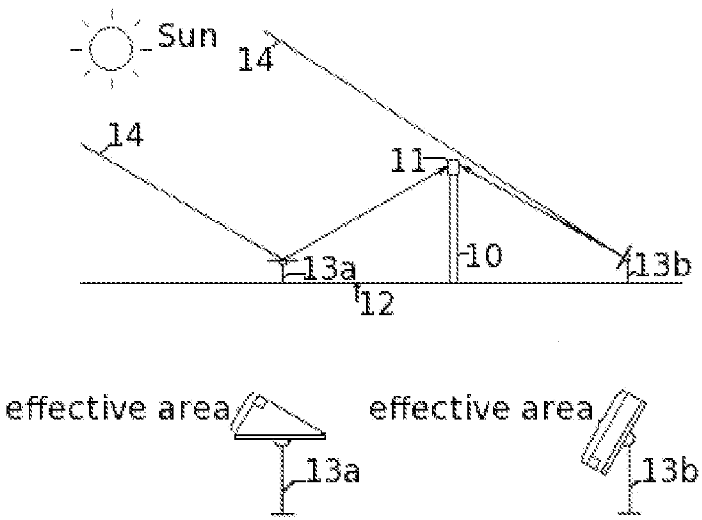
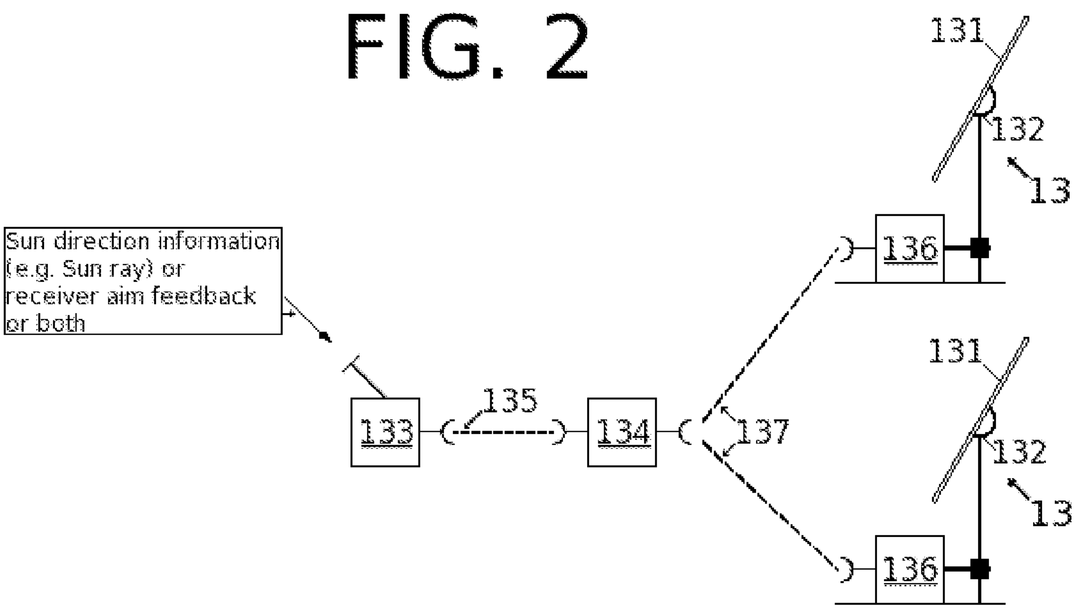

Sun
14
14
11
10
13a
12
13b
effective area
13a
effective area
13b

FIG. 1

FIG. 2


131
132
13
Sun direction information (e.g. Sun ray) or receiver aim feedback or both
136
131
132
13
135
133
134
137
136

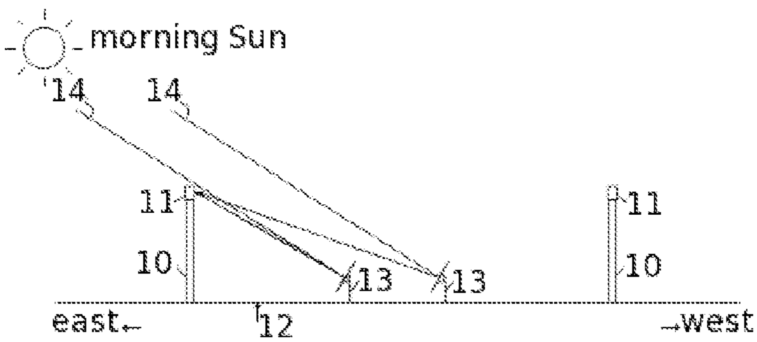

morning Sun
14
14
11
11
10
10
13
13
east←
12
→west

FIG. 3a

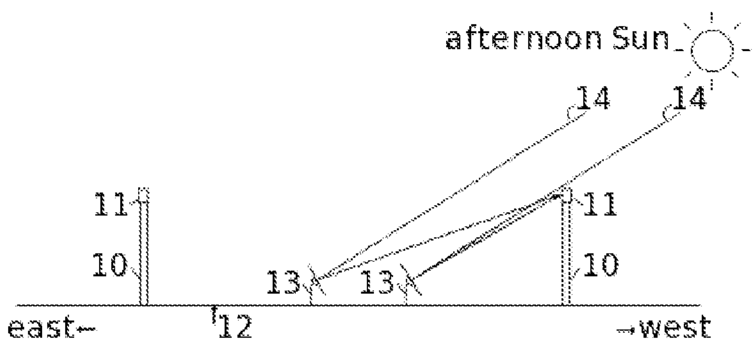
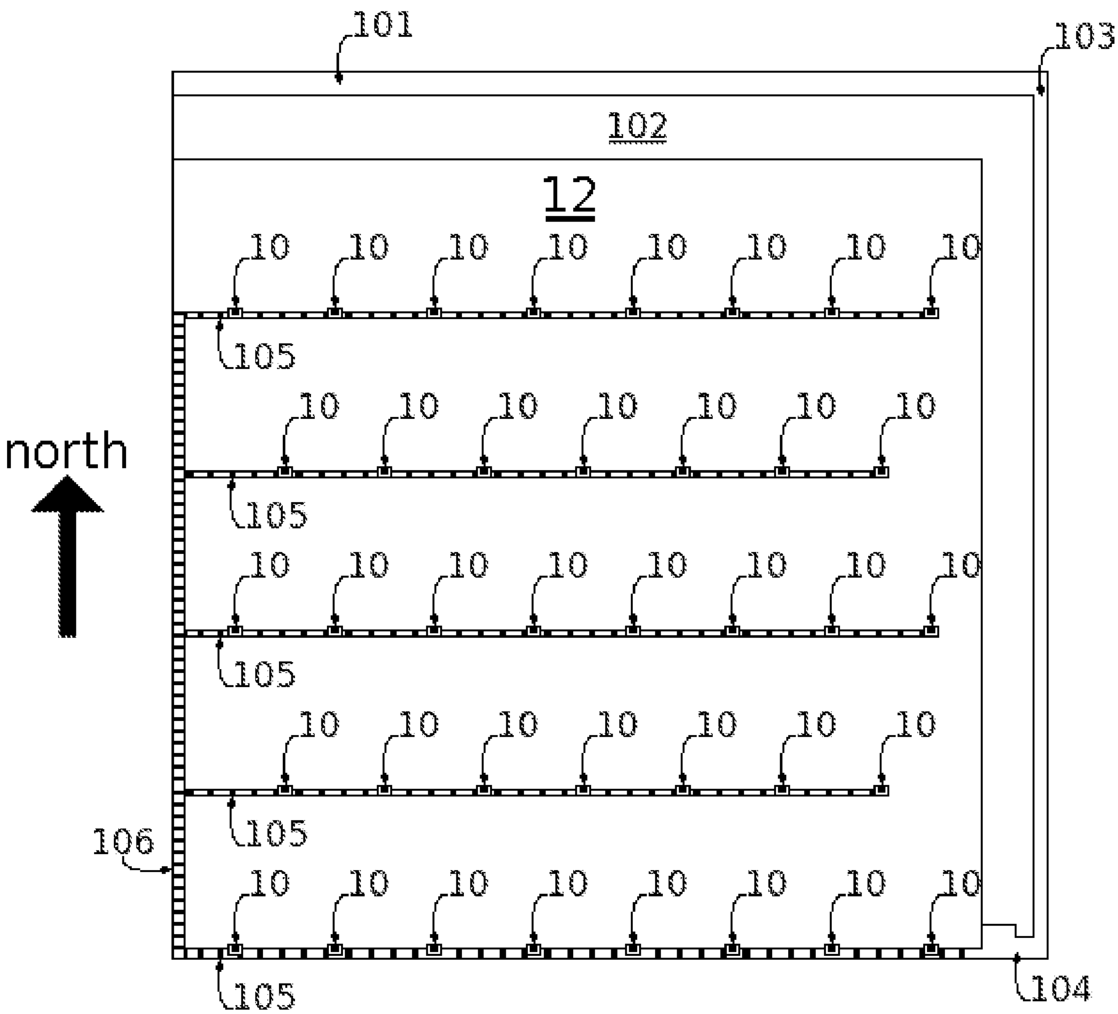

afternoon Sun
14
14
11
11
10
10
13
13
east←
12
→west

FIG. 3b

FIG. 4



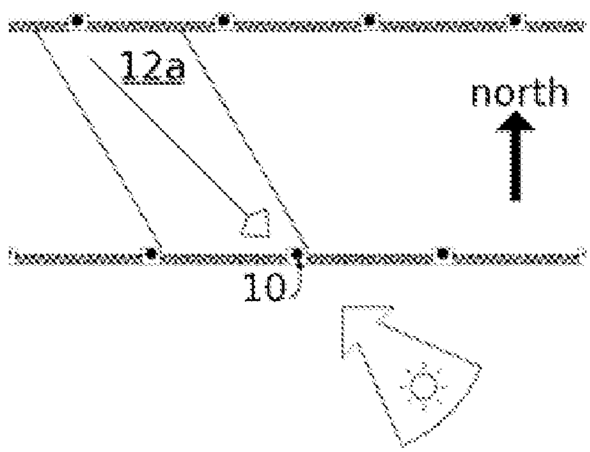


FIG. 5a

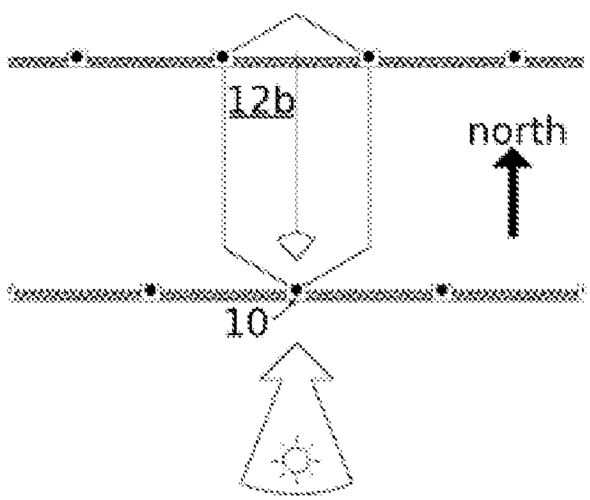


FIG. 5b

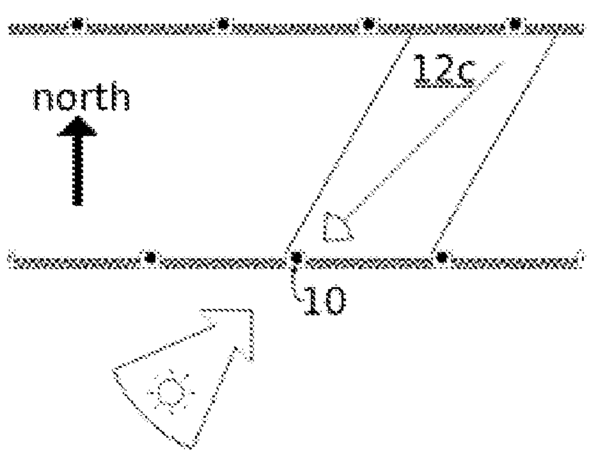


FIG. 5c

FIG. 6a

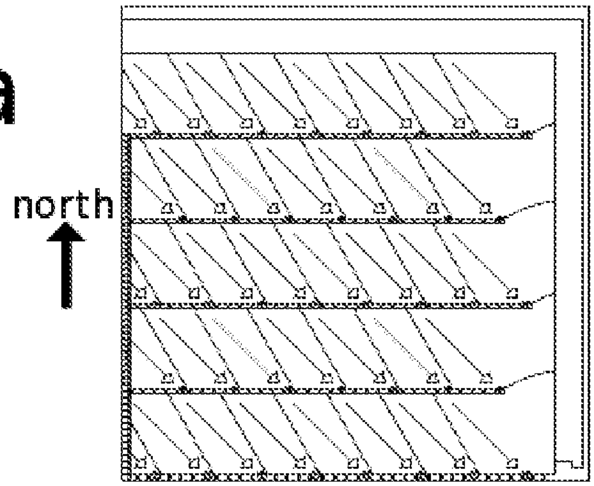


FIG. 6b

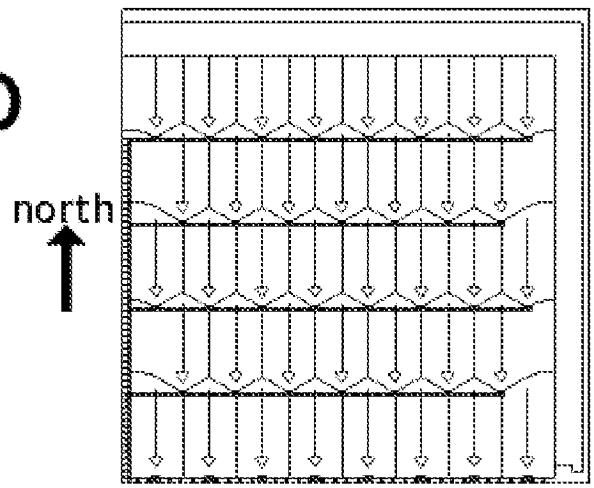
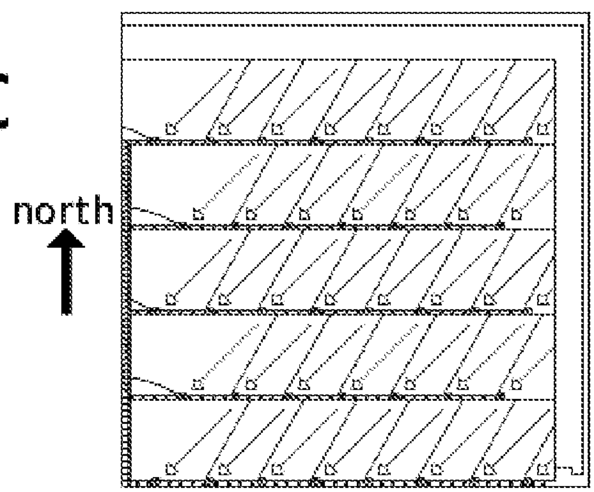


FIG. 6c



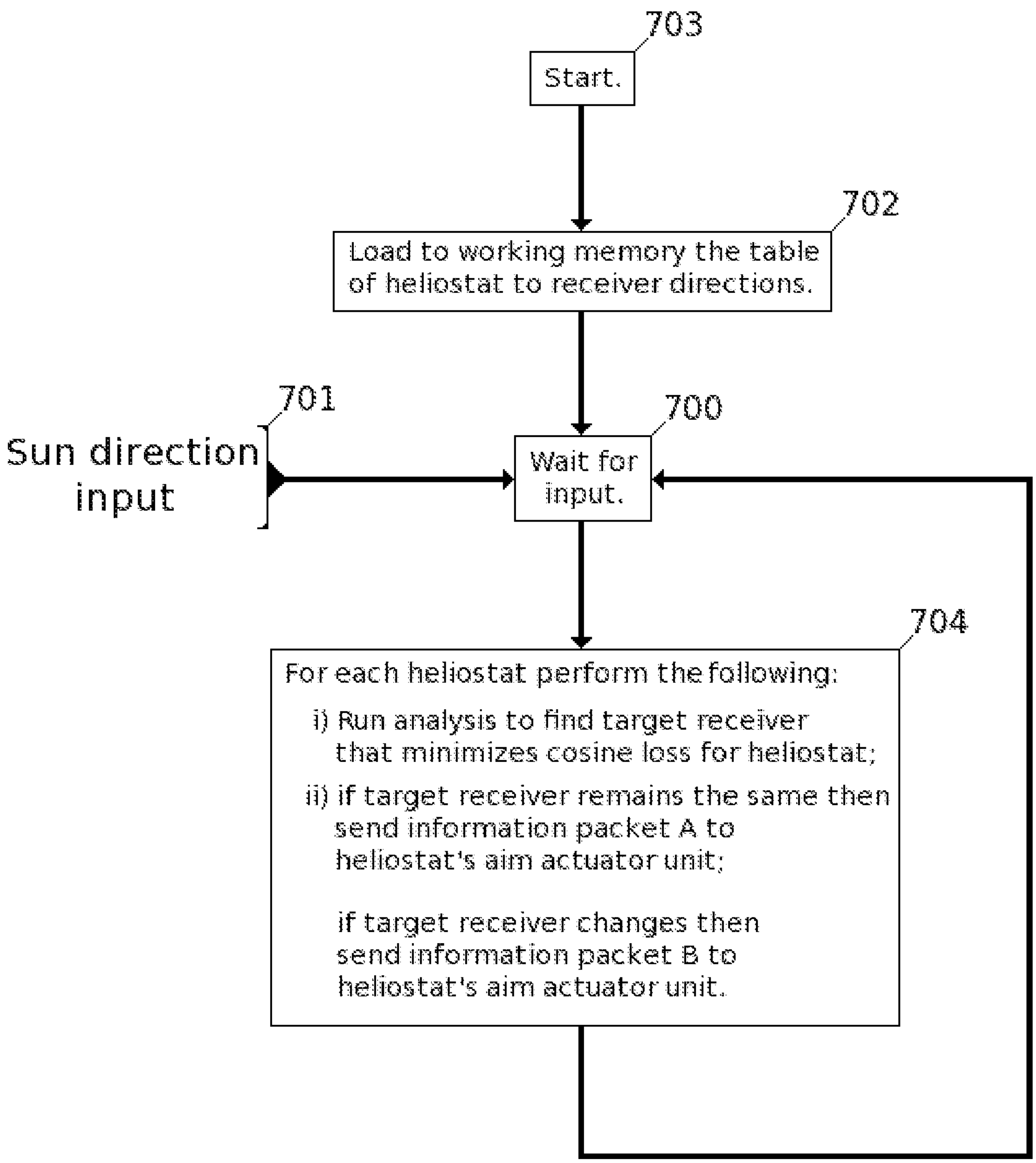

703
Start.
702
Load to working memory the table of heliostat to receiver directions.
701
Sun direction input
700
Wait for input.
704
For each heliostat perform the following:
i) Run analysis to find target receiver that minimizes cosine loss for heliostat;
ii) if target receiver remains the same then send information packet A to heliostat's aim actuator unit;
if target receiver changes then send information packet B to heliostat's aim actuator unit.

FIG. 7

DYNAMIC DISTRIBUTED TOWER RECEIVER SYSTEM FOR COLLECTING, AIMING AND RECEIVING SOLAR RADIATION

FIELD OF THE INVENTION

[0001] The invention relates to fields of heliostats and aiming reflected Sun rays at receivers.

BACKGROUND TO THE INVENTION

[0002] Central receiver systems and many other solar power technologies were first seriously considered in test projects, funded by national governments, in response to sharp rises in oil prices of the late 1970s and early 1980s. Stine and Harrigan wrote a useful summary of this work in Solar Energy Systems Design, (New York, N.Y.: John Wiley and Sons, Inc., 1985; accessible at http://www.powerfromthesun.net by William Stine and Michael Geyer).

[0003] Referring to FIG. **1**, a central receiver system solar power plant always includes as key elements radiation rays from the Sun (**14**), an absorber/receiver (**11**) for reflected solar radiation, a tower (**10**) to mount the absorber/receiver on, and a field of heliostats (**12**) that reflects and aims Sun rays at the absorber/receiver (**11**). The field of heliostats includes individual heliostats, for example **13***a* and **13***b*.

[0004] Now referring to FIG. **2**, each individual heliostat (**13**) has at least a mirror (**131**) held in or on a mount (**132**) turnable on two non-parallel (e.g. azimuth and inclination) axes. The field of heliostats also includes Sun direction tracking or receiver aim feedback device(s) or both (**133**), heliostat aim information processor(s) (**134**), means for communicating instantaneous Sun direction and/or receiver aim feedback to the aim information processor(s) (**135**), aim actuator units (**136**) that get aim direction signals and apply torques on the two minor turning axes to rotate the mirror according to the signaled aim directions and also means for communicating processed aim information to the aim actuators (**137**). There are several means for communicating between the elements **133**, **134** and **136**; for example, wired communication by transmission of digital or analog signals by electrical signals along wires or electro-magnetic radiation (e.g. light) along cables, or wireless communication by transmission of digital or analog signals by electro-magnetic radiation (e.g. radio waves) broadcast from transmitters and picked up by signal receivers or by what is here called "circuit neighbor transmission" by which two or all three of the major aim control elements (i.e. the control/information processing aspects of **133** and **136** and all of **134**) are housed within the same physical cabinet/box/container: In some heliostat field arrangements, a general purpose computer, housed in one box, could perform and communicate between all the control tasks of **133**, **134** and **136**, as could some customized field-programmable gate arrays (FPGA) or an application-specific integrated circuits (ASIC) when these last two are, at least, in communication with memory devices housed in the same containing box. A field of heliostats also needs mirror cleaning equipment (not shown).

[0005] There are numerous different realizations of heliostats and fields of heliostats. However, they might be categorized into two broad approaches. One is have all or most of the needed equipment for a whole field of heliostats at each individual heliostat, these heliostats tend to become very large (see, for example, Mancini, T. (2000). "Catalog of heliostats." Solar PACES Technical Report No. III-1/00). The other approach is to pare each individual heliostat down to minimal equipment (mirror surface and mounts with two rotatable axes) and then, when a minor movement is needed, for example, bring all the rest of the needed field equipment to the heliostat to make the mirror movement with, for example, robots on rails (U.S. Pat. No. 6,959,993 describes most of this functionality) or, as another example, drive the movement of a group heliostats, using collective turning rods or axes, from a group station handling tracking, information processing and aim control and with group motors for driving rod/axis rotations (U.S. Pat. No. 7,192,146 uses this approach).

[0006] A generic optical feature of any central receiver system power plant is that at any particular moment the effectiveness of most its heliostat mirrors is reduced from these minors' optimal effectiveness, this is usually called "cosine loss" (Bergeron, K. D. and Chiang, C. J. (1980). "SCRAM: a fast computational model for the optical performance of point focus solar central receiver systems," in technical report for Sandia National Laboratories; report number SAND-80-0433; US Dept. of Energy OSTI ID 5304143). Cosine loss is due to both the functional requirement that a heliostat minor be turned on it's two axes to an orientation that aims reflected Sun rays right at the absorber/receiver and that, when in this aiming orientation, the minor is, in most instances, turned away from the orientation at which it reflects its maximum cross section of Sun rays, i.e. when rays and minor are perpendicular. This sub-optimal variation in mirror effectiveness is illustrated in the lower "blow-up" areas of FIG. **1**: In its particular aim position heliostat **13***a* has an effective area much reduced from the area of the minor of heliostat **13***a*, in contrast, the effective area of heliostat **13***b* is very near its optimal effective area, the area of the mirror, because in its given aim orientation, the mirror of heliostat **13***b* is very nearly perpendicular to the Sun rays hitting it.

[0007] In a system with just one receiving tower, cosine loss makes some positions on a plant site more favorable for placing minors than other positions even though there is just as much sunlight falling on the unfavored positions. Referring to FIG. **1**, heliostats, like **13***b*, placed on the side of a central receiver system tower opposite the Sun's apparent position are favored by reduced cosine loss over heliostats, like **13***a*, positioned on the same side.

[0008] It is useful to consider this "opposite side" or "same side" distinction along north-south and east-west directions. Assuming the power plant is north of the Tropic of Cancer (for example, in the continental USA), along the north-south direction heliostats north of the tower are on the opposite side of the tower to the Sun's apparent position at (very nearly) all times the Sun is visible, while those on the south side of the tower are (very nearly) always on the same side of the tower as the Sun's apparent position. So, north of the Tropic of Cancer and when averaged over a full day, heliostats north of a plant's tower suffer less from cosine loss than those south of the tower; south of the Tropic of Capricorn (for example, in South Africa) this advantage changes to favoring south of tower heliostats. These, relative to a single tower, north-south direction, heliostat positional advantages stay fixed in time. In the east-west direction, relative to a single tower, some heliostats positions are favored to reduce cosine loss over other positions, however, in contrast, these heliostat positional advantages change in a daily time cycle.

[0009] With single tower plants, the north-south bias for reducing cosine loss favors fields of heliostats roughly symmetric about a north-south axis, longer along it than in the east-west direction and with the tower on the symmetry axis and away to the side from the heliostat field center, or outside it altogether (on the south side for a plant located in the Earth's northern hemisphere or on the north side of the site in the southern hemisphere). As central receiver system power plants go beyond their test and prototype phase, having significant functional bias of any kind toward any particular plant layout will cause tension with potentially significant land use, economic and political consequences. Functional biases toward particular central receiver system plant layouts can not always be expected to fit nicely with the existing local context.

SUMMARY OF THE INVENTION

[0010] The invention involves a time dependent method for reducing cosine loss from heliostat fields in receiver system solar power plants with not one but multiple towers and multiple receivers. In this method heliostats change which tower mounted receiver they aim reflected Sun rays through day times to reduce cosine loss. In preferred embodiments a field of heliostats of several tens of acres has many towers and receivers. These systems are called dynamic distributed tower receiver systems (DDTRS).

[0011] The method also utilizes heliostat field layouts that can extend in the east-west direction which not only reduce cosine loss but also fit and fill many different potential plant sites without wasting land that is good for solar energy collection. The site fitting and filling ability is not readily shared by one tower sites since there is no expectation that a particular site will coincide with one tower heliostat field shapes favored by function leading to some combination of underused land or underused plant equipment.

[0012] The ability to reduce cosine loss and fill a site with efficient solar energy collecting heliostats increases with the number of receiving towers on the site. This has another major benefit because with increasing number, the required height of the towers decreases and at a certain height, around 30'-50' (9 m-15 m) tall, the towers become similar to many other features in the landscape, for example farm buildings and trees. In this height range, the visual impact of a tower receiver system solar power plant becomes small and can be easily hidden or obscured by standard landscaping techniques, such as tree planting, and even productively hidden with agricultural planting such as orchards while wine vines can be used to obscure the lowest mounted heliostats now being made.

[0013] Reducing cosine loss and more completely filling a site with efficient solar energy collecting heliostats increases the amount of concentrated light collected per acre of solar power plant. Significant gains in the amount of concentrated light collected per acre have significant environmental, social and economic benefits. It is likely that in the next thirty years that millions, quite probably tens of millions, of acres of land in the United States will be covered with fields of heliostats. These acreages of valuable land taken by fields of moving mirrors can be cut with gains in the per acre amount of concentrated light collected.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a simplified, across-landscape, elevation view of the solar collecting front half of a generic central receiver system power plant.

[0015] FIG. **2** is a diagrammatic illustration of generic parts of a field of heliostats.

[0016] FIG. **3***a* is a simplified, across-landscape mid-morning view, looking south, of the solar collecting front half of a multi-tower receiver system power plant illustrating heliostat aiming that reduces cosine loss.

[0017] FIG. **3***b* is a simplified, across-landscape, mid-afternoon, elevation view, looking south, of the solar collecting front half of a multi-tower receiver system power plant illustrating heliostat aiming that reduces cosine loss.

[0018] FIG. **4** is a simple illustrative example plan layout of a dynamic distributed tower receiver system solar power plant on a 40 acre land plot with features commonly found in 40 acre plots in rural and urban outskirt areas in the USA.

[0019] FIG. **5***a* is a simple example diagram plan of an internal section of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating a mid-morning contiguous block of heliostats all aimed at a receiver on the same tower; the block is a visible affect of heliostat aiming to reduce cosine loss.

[0020] FIG. **5***b* is a simple example diagram plan of an internal section of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating an around-noon contiguous block of heliostats all aimed at a receiver on the same tower; the block is a visible affect of heliostat aiming to reduce cosine loss.

[0021] FIG. **5***c* is a simple example diagram plan of an internal section of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating a mid-afternoon contiguous block of heliostats all aimed at a receiver on the same tower; the block is a visible affect of heliostat aiming to reduce cosine loss.

[0022] FIG. **6***a* is a simple example diagram plan of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating mid-morning contiguous blocks of heliostats all aimed at common receivers for the block; the blocks are visible affects of heliostat aiming to reduce cosine loss.

[0023] FIG. **6***b* is a simple example diagram plan of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating around-noon contiguous blocks of heliostats all aimed at common receivers for the block; the blocks are visible affects of heliostat aiming to reduce cosine loss.

[0024] FIG. **6***c* is a simple example diagram plan of the field of heliostats of the dynamic distributed tower receiver system of FIG. **4** illustrating mid-afternoon contiguous blocks of heliostats all aimed at common receivers for the block; the blocks are visible affects of heliostat aiming to reduce cosine loss.

[0025] FIG. **7** is an exemplary flow diagram of a cosine loss reducing, decision-making and communication process.

DETAILED DESCRIPTION OF THE INVENTION

[0026] In across-landscape, diagram elevation views FIG. **3***a* and FIG. **3***b* two towers (**10**), each with a receiver (**11**), are shown in a multi-tower receiver system power plant with a heliostat field (**12**) and heliostats (**13**) between the two towers along the east-west direction (these elements need not fall on a single east-west line). The time period for FIG. **3***a* is mid-morning while that for FIG. **3***b* is mid-afternoon. A major difference between these two periods is that the heliostats between the two towers have changed which receiver they aim reflected Sun rays (**14**) at. This change in which tower/

receiver to aim at is such that at both time periods for FIG. **3***a* and FIG. **3***b* the heliostats (**13**) are on the opposite side to the Sun's current apparent position of the tower/receiver they are aiming at, a one tower central receiver system can not achieve this.

[0027] FIG. **4** shows an illustrative example plan layout for a dynamic distributed tower receiver system on a 40 acre (440 yard×440 yard) site that shares features with 40 acre plots found widely across the USA. The north side of the plot includes half the width of a 20 yard wide road (**101**) and a 28 yard wide strip (**102**) for both road edge/drainage area and an area that can be used to obscure the view of the field of heliostats, for example, with planting. The east of the plot is similarly edged but with a narrower road (**103**). In the south east corner of the plot access onto the (402 yard×407 yard) DDTRS site is gained from a track (**104**) leading off the narrower road. Five east-west tracks (**105**) and one west side, north-south track (**106**) provide access for maintenance vehicles to the heliostat field and thirty-eight towers (**10**) arranged along the east-west tracks. These towers are in a staggered grid of three rows of eight towers with each of these rows alternating with rows of seven towers. The east-west separation between these towers is 50 yards, while the north-south distance between rows is 80 yards and the east-west tower placement stagger between rows is 25 yards. Inside the DDTRS core site the entire region not covered by access tracks, the towers and narrow regions around the towers is given over to the heliostat field (**12**). The towers would be much shorter, close to 40' (12 m) tall, than is typical of central receiver system towers, now usually 250' (75 m) to 660' (200 m) tall. For simplicity, this illustrative site example is assumed to be free of any practically important changes in ground height.

[0028] In preferred embodiments, for all individual heliostats in a field, the choice as to which receiver to aim at is decided so that cosine loss is minimized at the particular time. Although this choice can be made for each individual heliostat and repeatedly throughout the day, this is a decision based on geometrical relationships and parallel decisions made for close neighbor heliostats are, most of the time, exactly the same and, thus, contiguous sections of a heliostat field will all be aiming at the same receiver at any given time when the criterion to minimize cosine loss is actually met. FIG. **5***a*, FIG. **5***b* and FIG. **5***c* are plan views of an internal part (away from the boundary) of the DDTRS site illustrated in FIG. **4**, and each of these internal part plans illustrate sections (respectively, **12***a*, **12***b* and **12***c*) of the field of heliostats all simultaneously aimed at one receiving top of one tower (**10**) at three different time periods of the day; i.e. FIG. **5***a* covers mid-to-late morning, FIG. **5***b* covers a period around noon and roughly through one hour before to one hour past noon and FIG. **5***c* covers early-to-mid afternoon.

[0029] FIG. **6***a*, FIG. **6***b* and FIG. **6***c* illustrate, across the heliostat field of FIG. **4**, the formation of contiguous sections of the field of heliostats, such that all heliostats in a given section aim reflected Sun rays at a single common receiver within the section and outside the section at another receiver. These contiguous sections are an affect caused by the field meeting the invention's criterion to minimize cosine loss and their shapes are also due to the regular grid layout of the tower/receivers of the example given in FIG. **4**. These figures cover different time periods of a day which are, as before, mid-to-late morning (FIG. **6***a*), roughly through one hour before to one hour past noon (FIG. **6***b*) and early-to-mid afternoon (FIG. **6***c*). In regions of the field of heliostats fairly close to its boundary the individual heliostats have fewer good receiver locations to make minimizing cosine loss choices from and the contiguous sections tend to get bigger than those in internal regions of the heliostat field away from the boundary. During the main part of the day, when insolation (sunshine intensity) is high, the shapes of these contiguous regions change slowly, like the change in a tree shadow around noon. However, just after dawn and just before dusk, optimal contiguous region configurations change more rapidly. Like the lengthening of shadows around dusk, the optimal solutions go from concentrated light being aimed at all tower receivers on the site to just those tower receivers closest the dusk side edge of the site; while, just after dawn, the optimal solution again goes to aiming at just a few of the tower/receivers but now toward the dawn side edge of the site.

[0030] Lining up receivers on towers along rows in the east-west direction, with equal separation between the towers along this direction and equal separation between the rows in the north-south direction is preferred. However, variant plant layout plans with small deviations away from a grid pattern or east-west orientation are nearly as good as the preferred layout: A five degree row rotation away from a strict east-west row orientation would hardly hinder system performance at all; while local site factors (for example, the site boundary shape) could well favor rows rotated twenty or thirty degrees from a strict east-west row orientation both for improving the fit of the DDTRS into the local context and also for improving overall DDTRS performance (for example, by fitting more minor surface onto the site). So, the strength of preference is weak relative to small deviations from the grid arrangement and east-west orientation. The 80 yard tower row separation and 50 yard along row tower separation of the example of FIG. **4** are not generally preferred, rather, these distances only become sensible due to the particular size and shape of the FIG. **4** example site (with a 400 yard×400 yard field of heliostats) and, also, due to the example's use of 40' (12 m) tall towers. So, for example, if 52' (16 m) tall towers are used instead but on the same, FIG. **4**, site then a 100 yard tower row separation and 80 yard along row tower separation would be better. While, if the field of heliostat's were on a 350 yard×350 yard site then using a 70 yard tower row separation and 50 yard along row tower separation and 40' (12 m) tall towers would be sensible.

[0031] Construction of a receiver system includes a calibration phase carried out when all the major elements (tower, receiver, and heliotstats) are firmly in place. Calibration obtains accurate directions between heliostats and receivers. A DDTRS also needs calibration, the only practical difference with prior art is that accurate directions are needed between all the heliostats and all the receivers on all the DDTRS's towers, rather than just one tower. In preferred embodiments re-calibration is ongoing to take into account changes due to ground movement and structure deformation. The initial calibration and re-calibrations need to produce a table of accurate direction vectors between each heliostat and each receiver. Further, in preferred embodiments, this table of directions needs to be put in a format that can be stored on a computer or accessed by another integrated circuit device, such as a field-programmable gate array (FPGA) or an application-specific integrated circuit (ASIC), that can implement heliostat aim control programs. In preferred embodiments, the specification of the directions would either be a two angle vector (for example, azimuth and inclination angles) or a three dimensional Euclidean unit vector.

[0032] To decide on which receiver to aim at to minimize cosine loss, a DDTRS does computations to find out what a heliostat's cosine loss would be if it were to aim at any one of the receivers. To carry out these computations a DDTRS needs the instantaneous apparent Sun direction. There are prior art ways to obtain the apparent Sun direction including direct Sun tracking and analytical methods based on Newton's laws, some solar system facts, the longitude and latitude coordinates of the DDTRS site and the current time.

[0033] Prior art receiver systems already make heliostat aim decisions in a time dependent way and use mechanicals that can re-aim heliostat minors with turns along two axes: These re-aims are of two kinds (a) a once a day large-turn reset from the dusk orientation back to the dawn orientation of a new day and (b) small adjustments to account for small changes in the daytime Sun's apparent position on sub-minute to few minute time scales. A DDTRS uses this prior art but adds heliostat re-aiming to a new target receiver whenever a cosine loss minimization decision indicates that aiming at a new target receiver will reduce cosine loss. FIG. **7** gives an exemplary time flow diagram indicating how cosine loss minimization decisions and re-aims to new target receivers could fit into the series of small aim adjustments needed due to minute-to-minute changes in the Sun's apparent position. This decision making is implemented through a program run on an integrated circuit capable of running the program, such as an FPGA, an ASIC or the CPU of a general purpose computer. Most of the time the program is simply waiting (**700**) for Sun direction input (**701**); the other main input for the program, the table of heliostat to receiver aim directions is loaded (**702**) just once after the program is started (**703**). The Sun direction inputs should come in at time intervals of roughly between 15 seconds and 5 minutes. These time intervals do not have to be equal to each other but can be. For the longer time intervals, as they get longer still the average fraction of on-target reflected light from the heliostat to receiver goes down, reducing the temperature at the receiver. So, the time intervals have to be short enough that the receiver can maintain the temperature needed for the plant process it drives. Using much shorter time intervals than is required will increase the rate of wear on the mechanicals actuating the heliostat rotations with no practically useful increase in receiver temperature. The input of a Sun direction triggers the implementation of a decision-making and communication process (**704**) that for each heliostat runs an analysis to find the receiver that, if the heliostat reflects Sun ray's to it then, the heliostat's cosine loss is smallest among all the receivers it can target. These analyzes use standard techniques of analytic geometry and linear algebra and can be run thousands of times in much less than a second total. An extending variation is used for cases where a single aim actuator unit aims a group of heliostats. This variation is such that change of target receiver decisions covering the entire group are based on the cosine loss minimizing target aim receiver decisions for the heliostat closest to the group's plan middle.

[0034] The process (**704**, FIG. **7**) also sends out information packets to the aim actuator units (**136**, FIG. **2**) of the heliostats, located all around the field of heliostats, and these information packets hold instructions for telling the aim actuator units how to re-aim their heliostats. For a DDTRS, the information packets cover two cases. In one case (referred to as packet A in FIG. **7**), the target receiver remains the same as for the (15 seconds to 5 minutes) prior Sun direction input and in this case the heliostat aim actuator unit receiving the information packet carries out the re-aim in the same way a prior art central receiver system would. This prior art re-aim would be one of two kinds. Either the heliostat re-aims using a feedback information system, U.S. Pat. No. 7,906,750 describes a system that could do this in "closed loop tracking" mode which is like doing calibration continuously. Alternately, trusting the system's reference direction vectors are well calibrated, the information packet A just contains a direction vector and the heliotstat's aim actuator unit makes small mirror turns according to this direction vector. In the other case (referred to as packet B in FIG. **7**), the target receiver changes from the prior Sun direction input, and with this, if the aim actuator unit sent the information packet B is always directed by direction vectors then packet B contains a direction vector that indicates a re-aim to the new target receiver; alternately, if the aim actuator unit can re-aim using a feedback system then it's necessary, for the aim actuator unit to be used in a DDTRS, for it also to be able to re-aim using direction vectors and be able to switch between the two re-aim methods and, again, packet B contains a direction vector indicating a re-aim to the new target receiver and the aim actuator unit needs to be able to re-aim on this information (the example of U.S. Pat. No. 7,906,750 is capable of re-aiming both with feedback and direction vectors).

The invention claimed is:

1. An apparatus and method, called a dynamic distributed tower receiver system, for collecting, aiming and receiving concentrated solar radiation, comprising:
- a field of heliostats;
- two or more towers located within or adjacent to the field of heliostats;
- two or more receivers mounted on top of two or more towers in or adjacent to the field of heliostats and to which the field of heliostats can reflect and aim Sun rays;
- one or more calibration tables holding all heliostat to receiver direction vectors;
- means for obtaining the Sun's apparent direction repeatedly in day times;
- making decisions, repeatedly in day times, of which receiver heliostats should aim reflected Sun rays at, not usually the same receiver for all heliostats;
- neighbor circuit or wired or wireless transmission of the receiver aim decisions to the field of heliostats' aim actuator units; and
- implementation of the receiver aim decisions by the field of heliostat's aim actuator units.

2. The apparatus and method of claim **1** additionally comprising:
- one or more memory devices that can store calibration tables of heliostat to receiver direction vectors and allow electronic access to such calibration tables to integrated circuit devices that can implement logical and analytical programs; and
- one or more integrated circuit devices, for example field-programmable gate arrays (FPGA), application-specific integrated circuits (ASIC), CPUs of general purpose computers, to implement logical and analytical programs that make aim decisions about which receiver heliostats should aim reflected Sun rays at and initiate transmission of such aim decisions.

3. The apparatus and method of claim **2** wherein means for obtaining the Sun's apparent direction repeatedly in day times is implemented in a logical and analytical program, based on Newton's laws, some solar system facts, the longitude and latitude coordinates of the DDTRS site and the current time, and run on the integrated circuit devices running logical and analytical programs that make aim decisions.

4. The apparatus and method of claim **2** wherein means for obtaining the Sun's apparent direction repeatedly in day times is a prior art Sun tracking device that can electronically signal one or more of the integrated circuit devices running logical and analytical programs that make aim decisions.

5. The apparatus and method of claim **2** wherein, for heliostats moved individually by an aim actuator unit, the heliostat to receiver aim decisions are made such that the cosine loss of each heliostat is minimized over the choice of receivers to aim at.

6. The apparatus and method of claim **2** wherein, for groups of heliostats that are moved collectively by a group aim actuator unit, the heliostat group to receiver aim decisions are made such that the cosine loss of the heliostat closest to the group's plan middle is minimized over the choice of receivers to aim at.

7. The apparatus and method of claim **1** wherein the receiver aim decisions are repeated in day time intervals not exceeding 5 minutes.

8. The apparatus and method of claim **1** wherein the calibration table is revised with remeasured calibration direction vectors between the heliostats and receivers after known ground moving and structure moving events such as earthquakes, high winds, flooding, mudslides, explosions, fires, above and below ground local structure collapse, vehicle accidents, heavy vehicle traffic, stampeding herds of animals, pile-driving, digging, earth grading and earth or rock moving for construction or mining.

9. The apparatus and method of claim **1** wherein the calibration table is revised with remeasured calibration direction vectors between the heliostats and receivers at least every five years.

10. The apparatus and method of claim **1** wherein the number per heliostat field area density of towers, with receivers mounted on top, is in excess of 1 tower for every 4 acres (1.6 hectares) of heliostat field.

11. The apparatus and method of claim **10** wherein the towers, including top mounted receivers, are less than 90 feet (27.4 m) tall, excluding tower parts intentionally buried below ground.

12. The apparatus and method of claim **11** wherein the number per heliostat field area density of towers, with receivers mounted on top, is in excess of 1 tower for every 1.5 acres (0.6 hectares) of heliostat field.

13. The apparatus and method of claim **12** wherein the towers, including top mounted receivers, are less than 50 feet (15.2 m) tall, excluding tower parts intentionally buried below ground.

14. The apparatus and method of claim **13** wherein the heliostats are not more than seven feet (2.13 m) tall with any heliostat mirror orientation, excluding heliostat parts intentionally buried below ground.

15. The apparatus and method of claim **10** wherein the towers, on top of which receivers are mounted, are aligned roughly or exactly in rows and roughly or exactly in an east-west direction.

16. The apparatus and method of claim **15** wherein towers aligned along a single row are roughly equally spaced along that row.

17. The apparatus and method of claim **16** wherein the rows the towers are aligned on are roughly equally separated on the north-south direction.

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