# APPENDIX F

## Glare Analysis for Ground Traffic

April 11, 2011

Good Company
65 Centennial Loop, Suite B
Eugene, Oregon 97401

Mr. Thomas Buttgenbach
88FT 8ME LLC
10100 Santa Monica Blvd, Suite 300
Los Angeles, CA 90067

Dear Mr. Thomas Buttgenbach:

The purpose of this technical memo is to augment the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report. *The Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report analyzed the 88FT project as being constructed in one phase and under one conditional use permit. However after completing the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report, the project's construction plan was modified to reflect a second conditional use permit that would allow the project to be constructed in more than one phase. We have reviewed and analyzed this modification and have determined that the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report remain unchanged. In other words, the development of the project in more than one phase or CUP does not change the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report. Please call me if you have any questions.

Joshua Skov

Principal, Good Company

**Potential Impacts from Reflection of Proposed Calexico Solar Farm I**
Draft Date: July 8, 2011

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**KEY FINDINGS**

- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection above the built environment and nearby traffic corridors.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Calexico Solar Farm I, which is located 5 miles west of Calexico in Imperial County, California. The project site is comprised of seven parcels of land with a total area of 1,333 acres. See Appendix A for aerial photographs of the site.

The proposed project is a ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the proposed Calexico Solar Farm I on nearby roads, buildings. The reflection impacts on aircraft using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

## Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules. Photovoltaic panels are using the absorbed energy in two ways; 1) the panels generate electricity, and 2) the mass of the panels heat up.

In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

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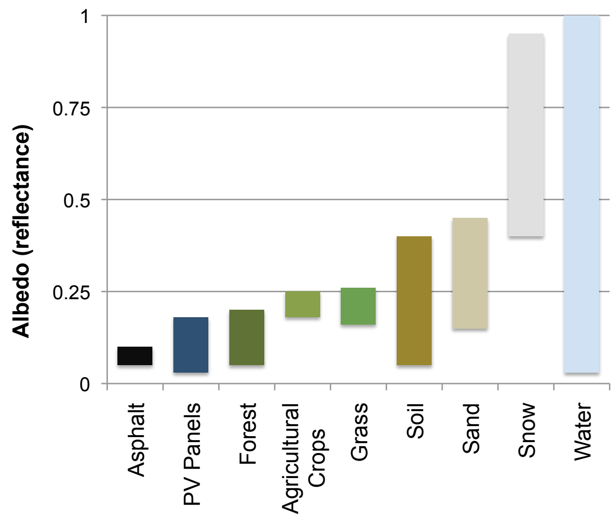
[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.
[2] Ibid.

## Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around 0.10.[3] By comparison, sand has an albedo between 0.15 and 0.45 and agricultural vegetation has an albedo between 0.18 and 0.25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

**Figure 1:** Albedo comparison for various surfaces.




## Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

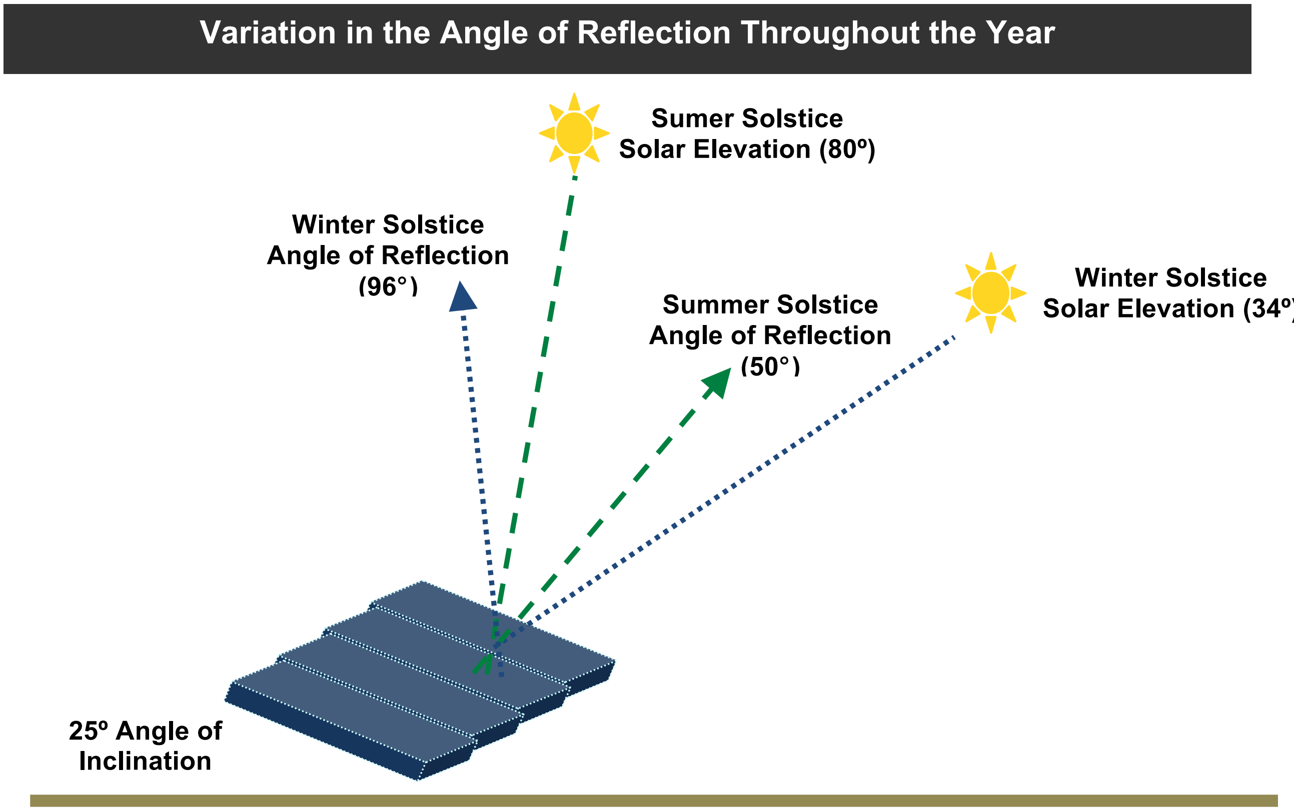
The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs midday on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 2 below). The potential impact at that moment is the best proxy for maximum impact overall.

During summer solstice at the proposed project's latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is unlikely that any objects in the built environment near the project site would be adversely affected by a direct reflection of sunlight from this angle, including vehicles traveling on nearby roads or houses south of the project site.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed project's latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.39 degrees north.

**Figure 2:** The range of the sun's angle-of-reflection depending on the time of year.




The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 20 feet (the approximate distance from the southern edge of the Calexico Solar Farm I project, array sections Parcel II and Parcel III, to the edge of Anza Road), the height of the reflected sunlight from the array would be nearly 24 feet in elevation, well above the California truck height limit of 14 feet. It's important to note that Anza Road and other roads in the immediate vicinity of the proposed arrays are not major transportation corridors and as such are not expected to support significant passenger or commercial traffic. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project, further obscuring the peripheral view of the project (and any indirect reflection).

There is a house located south of the Calexico Solar Farm I, below the Parcel II arrays. The house is 250 feet south of the proposed arrays. At this distance, the height of direct reflection is 298 feet, the height of a 20-story building[6].

[6] This number of floors assumes a height of 15 feet per floor.

Figure 3: Map of the points listed in Figure 4 and the “on the ground” distance from each point to the array.

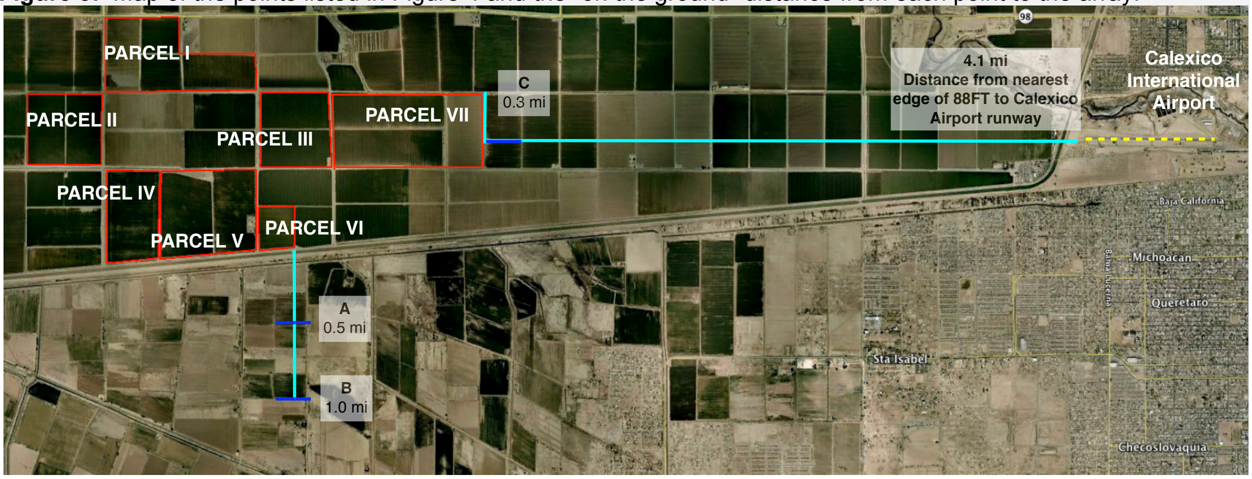



**Figure 4:** Elevation of direct reflection for the points shown on Figure 3.

| Point on Figure 3 | Elevation of Direct Reflection miles | feet |
|---|---|---|
| A | 0.60 | 3,147 |
| B | 1.19 | 6,294 |
| C | 0.36 | 1,890 |

## Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[7]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[8]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project.

## Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array the greatest potential for a low angle of reflection, that might impact the built environment, occurs midday on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At midday on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

[7] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see “Panache Valley Solar Farm Project Glint and Glare Study” (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and “Topaz Solar Farm Reflection Study” (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).
[8] TrinaSolar. “Reflection Coefficient of Trina Solar Modules.” Personal communication with Thomas Houghton, June 30, 2010.

## Appendix A: Glare Analysis Explanation

### Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[9] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

**Figure 7:** Angle of direct reflection on summer solstice (June 21).

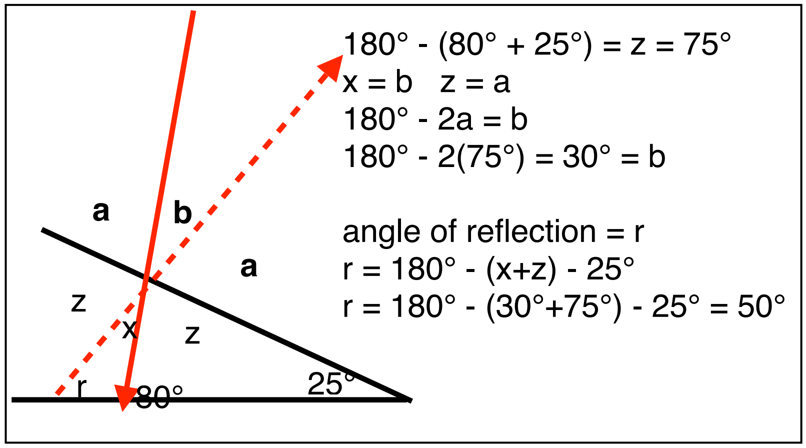
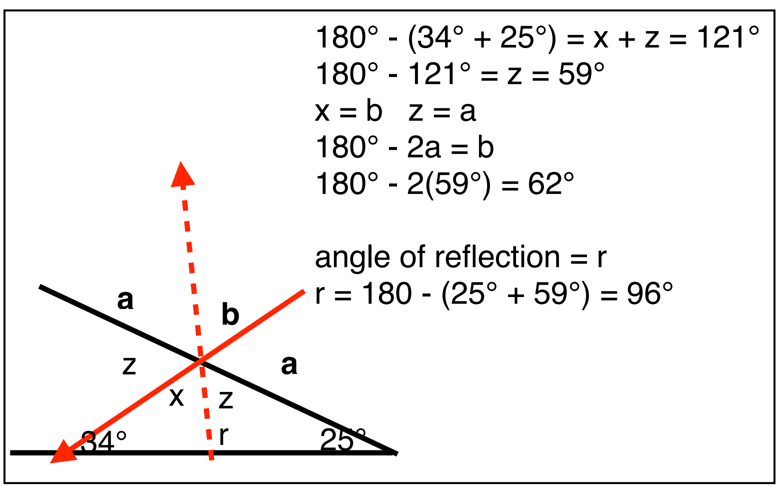



Figure 7 to the right depicts this reflection. All angles within a triangle summed equal 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

**Figure 8:** Angle of direct reflection on winter solstice (Dec. 21).



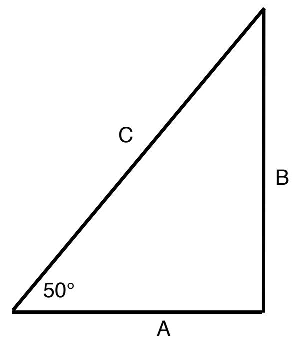

Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point during winter solstice on December 21st (see Figure 8, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[9] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

## Determining the Height of Reflection

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Calexico Solar Farm I. Figure 9 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

**Figure 9:** Calculation to determine direct reflection.

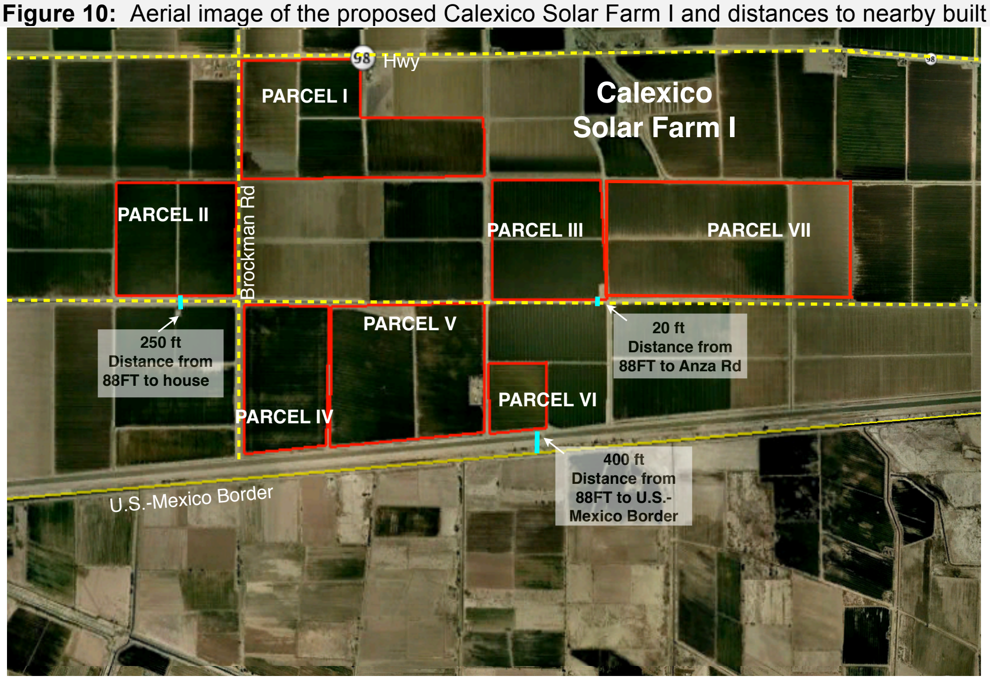



$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 10 is an aerial picture of the sited Calexico Solar Farm I from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico Border (yellow line) as well as the four portions of the project which serve as the boundaries for the panel arrays in this project. Figure 10 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 10 describe the height of the direct reflection at the various distances shown by the blue lines.

**Figure 10:** Aerial image of the proposed Calexico Solar Farm I and distances to nearby built structures and roads.

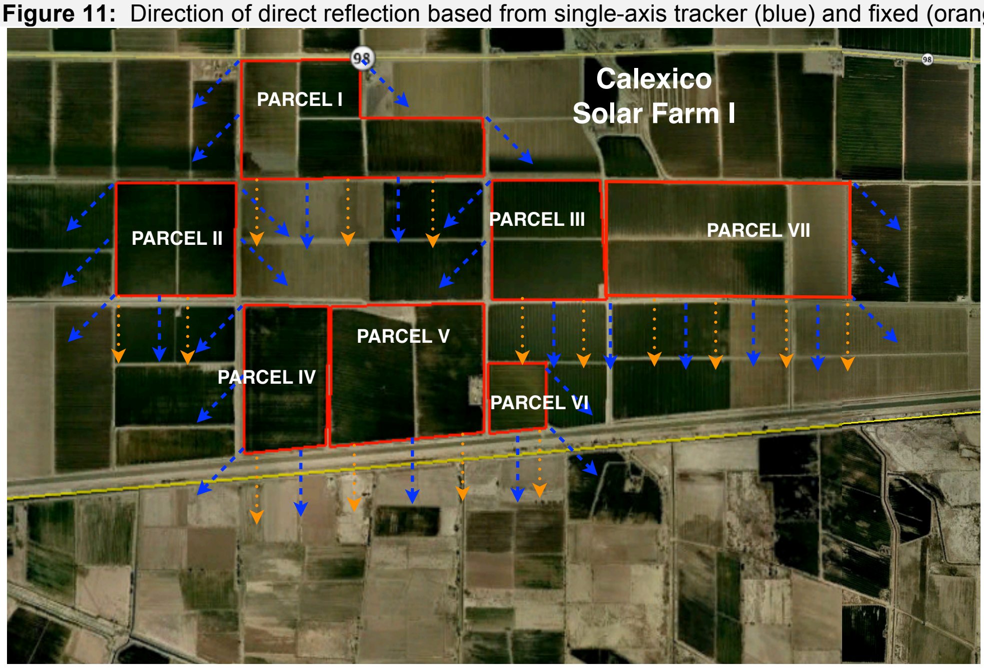



- At 20 feet from the solar panels the height of the reflection is already at 24 feet.
- At 250 feet from the solar panels the height of the reflection is 298 feet or higher.
- At 400 feet from the solar panels the height of the reflection is 477 feet or higher.
- See the Reflectivity Analysis conducted by Aztec Engineering for details on potential impacts to aircraft utilizing Calexico International Airport.

## Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

**Figure 11:** Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).



# APPENDIX G

## Glare Analysis for Air Traffic

# CALEXICO Solar Farm I (88FT 8ME, LCC)

# REFLECTIVITY ANALYSIS

REVISION INDEX

| Page/Reason | REV | Date | PROD | CHECK | APRV |
|---|---|---|---|---|---|
| All | 0 | 04/13/2010 | JDL | JDL | JDL |
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# Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to a series of photovoltaic (PV) power plants being developed by 88FT 8ME, LLC. Project location is nearby the Calexico airport in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the corresponding airport runway if reflected sun light beam intersects the approaching flight path.

Fig. 1 shows the location of the future PV plant relative to Calexico airport.

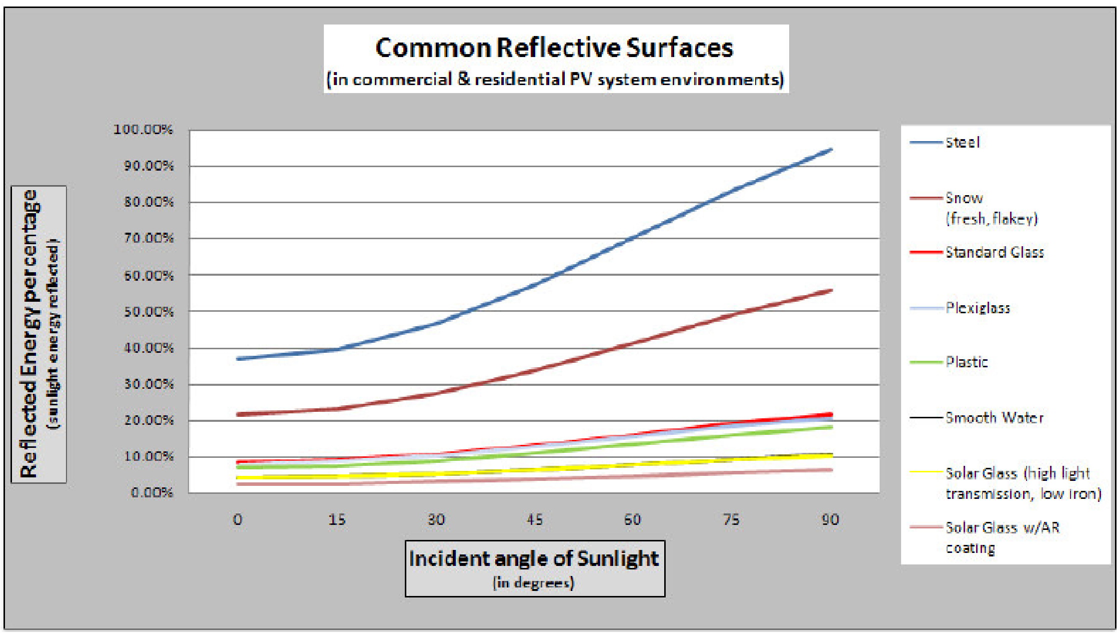

*Fig 1.- Location of PV Project and Calexico airport*

To evaluate the risk of direct sun light reflection events a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer direct reflection.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of the study:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the

reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and have negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules, for instance agricultural environment has higher Glare effect than PV modules.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to the airport runway.

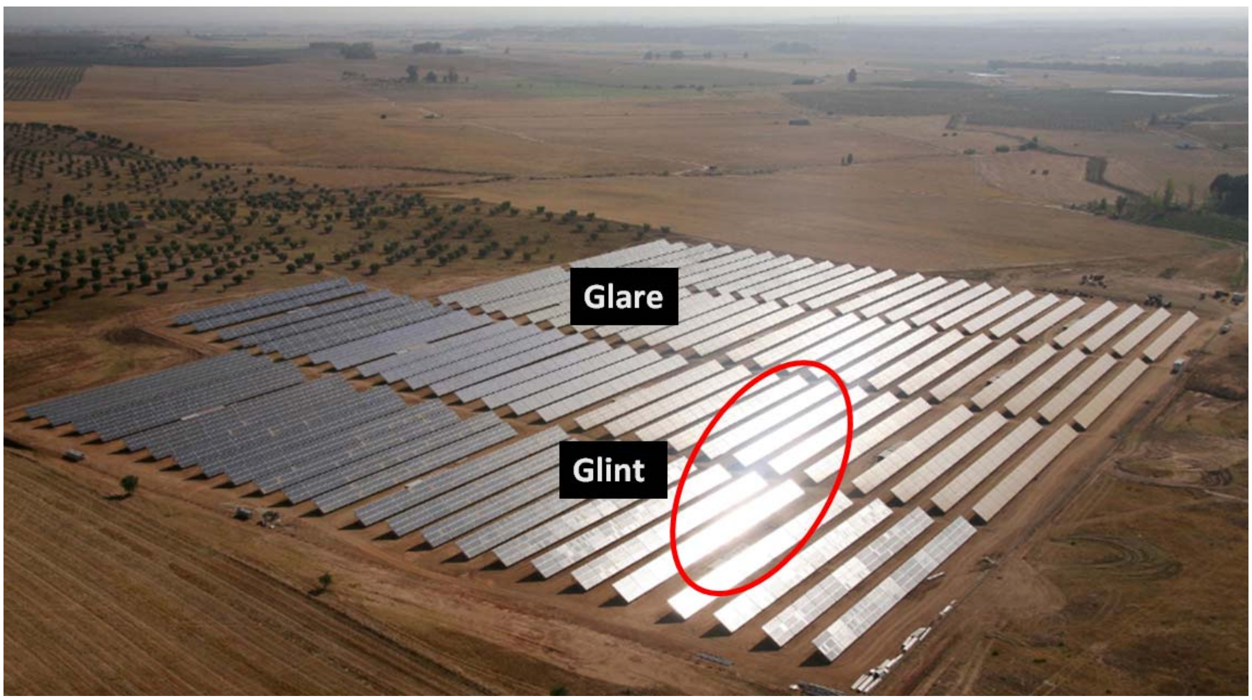



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Mathematical analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the future PV plant location, as shown in Fig. 3 below:


*Fig 3 .- Reference coordinate system*

Next image shows a 3D rendering of the future project

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

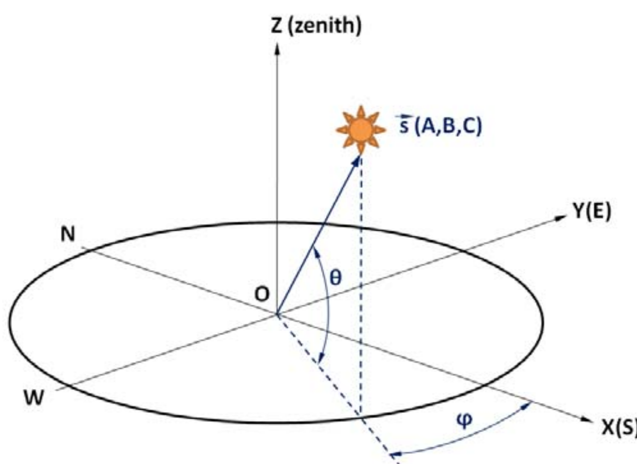



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta \ \cos\varphi$$
$$B = -\cos\theta \ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:
Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32,… until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc).
As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in the next graph:

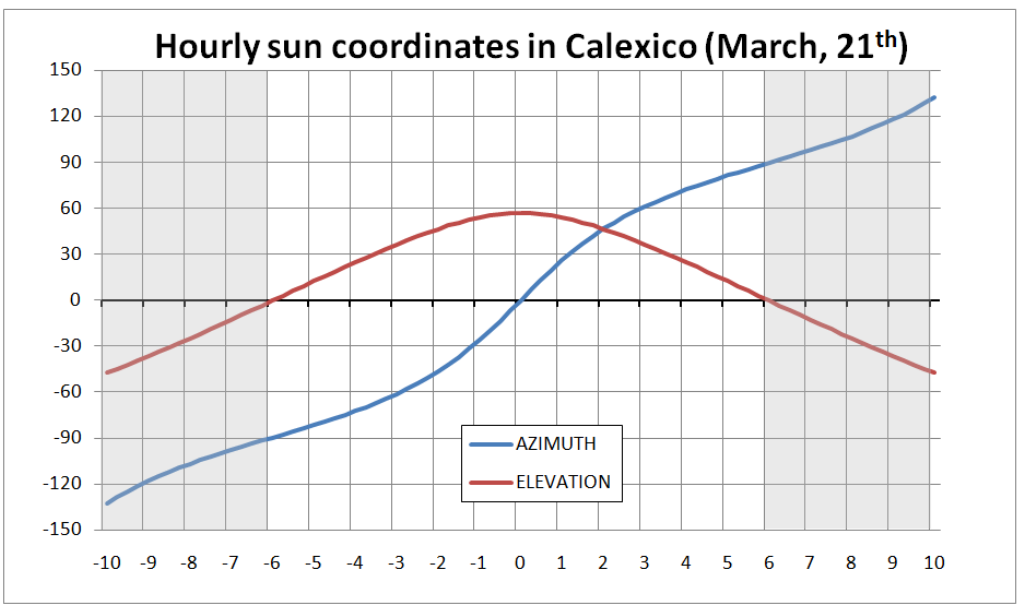



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

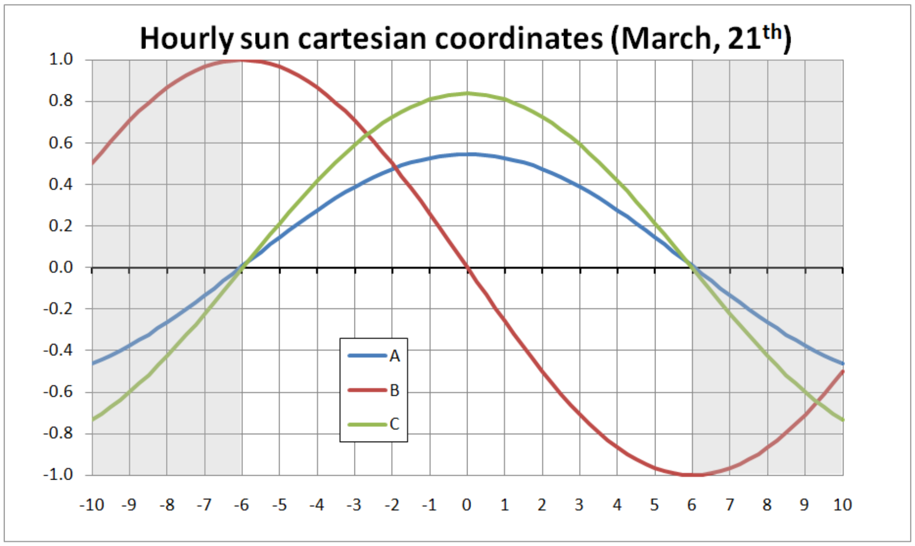



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located at the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

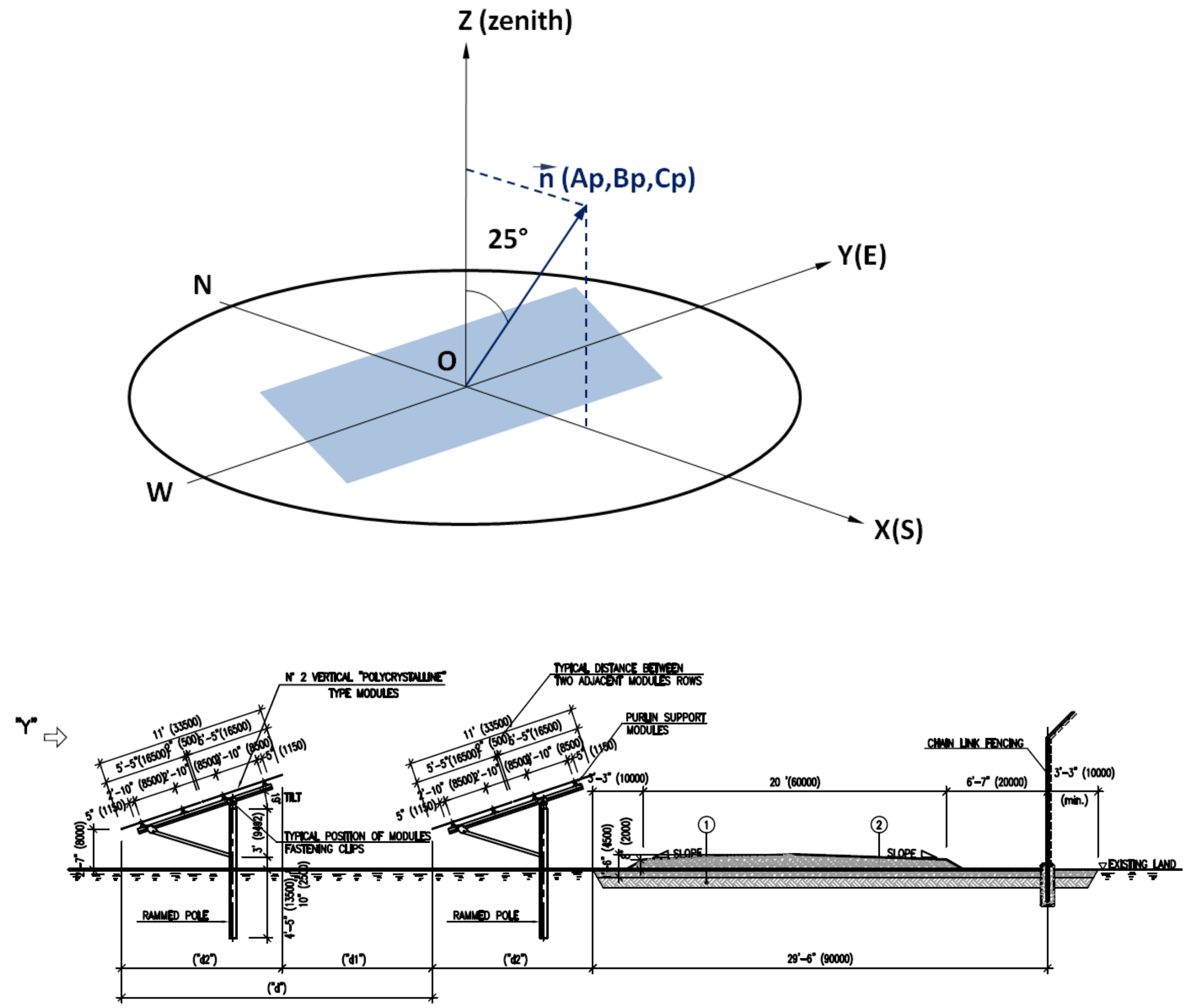



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:

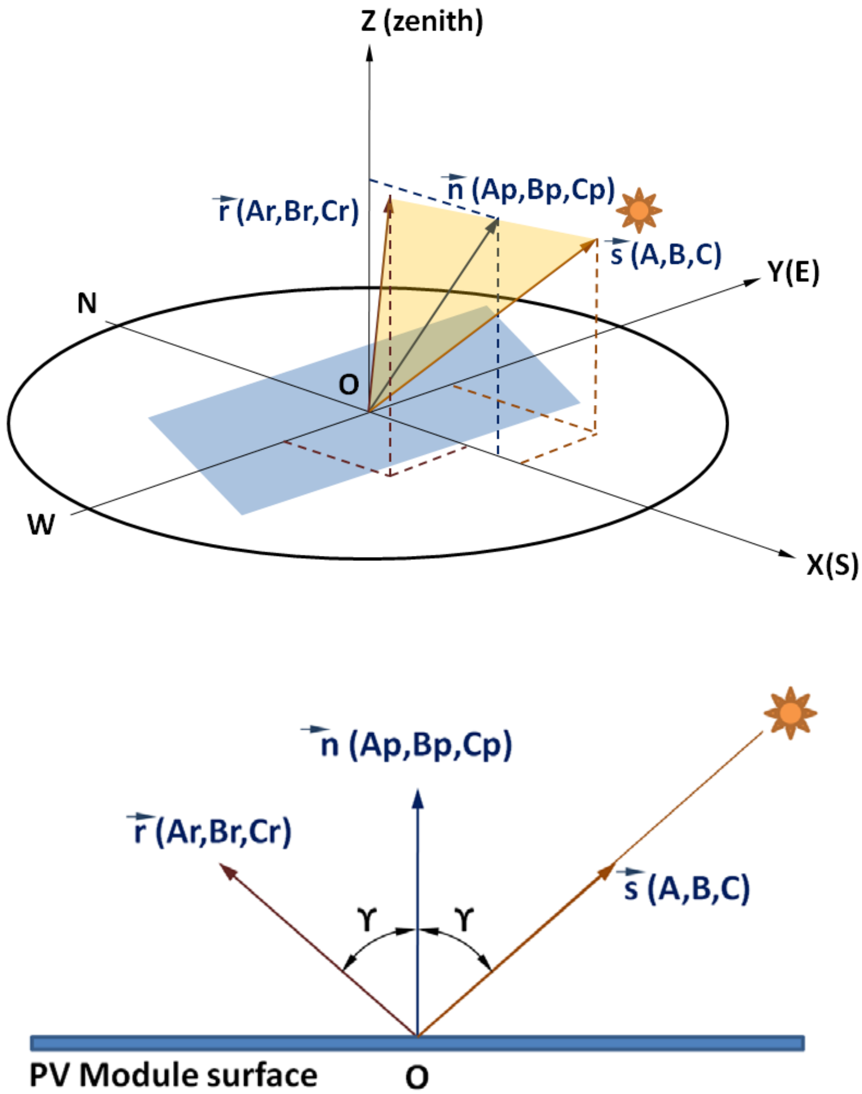



*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\,\vec{n} - \vec{s}$$

and its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\,A_p - A$$
$$B_r = 2\ \cos\gamma\,B_p - B$$
$$C_r = 2\ \cos\gamma\,C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

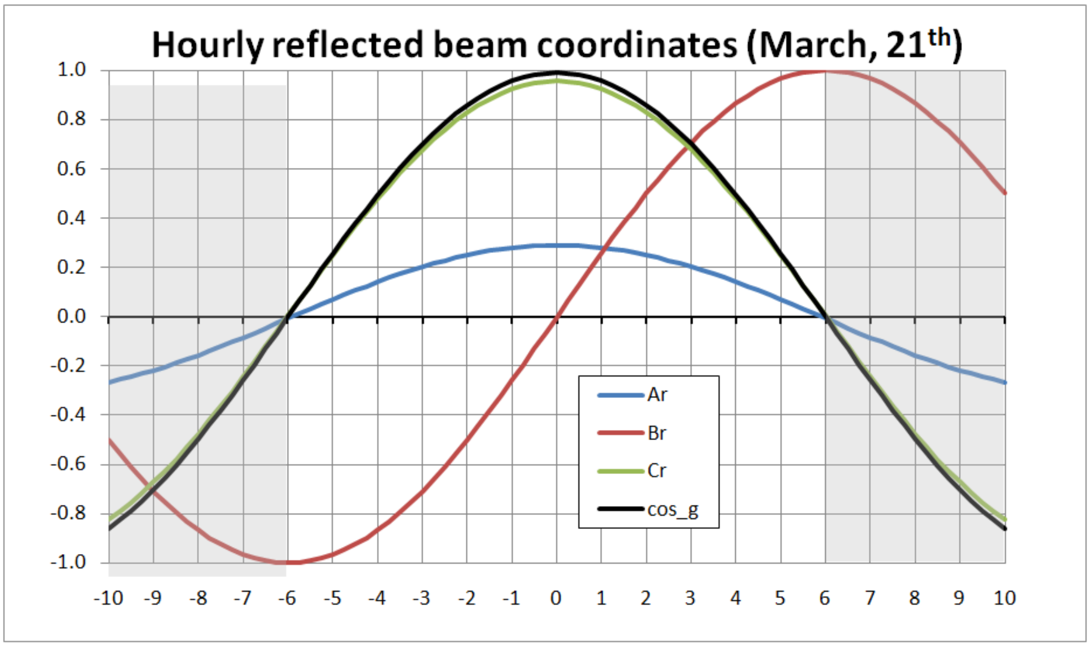



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity at Calexico runway (fixed systems)

To define the location of relevant KVP it is hereby assumed that the approaching airplane follows a straight line contained in a vertical plane (the “flight plane”) that also contains the runway axis (Fig. 10).

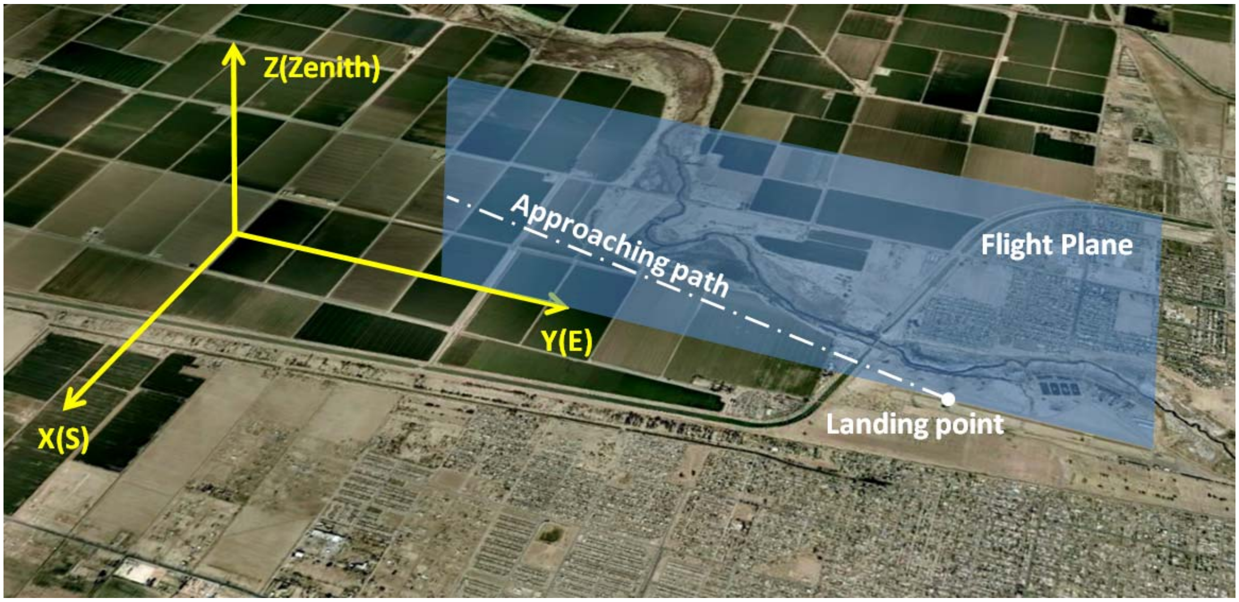



*Fig 10.- Geometry of approaching path*

The vertical flight plane, containing the approaching path, is defined by the following equation in the reference Cartesian axis system:

$$\Pi \equiv 0.9997\ x - 0.0239\ y = 0$$

The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

Runway azimut is 88.63°. Cartesian coordinates for any reflected beam r = (Ar, Br, Cr), if contained in the flight plane, shall satisfy the following condition (beam azimuth):

$$\frac{B_r}{A_r} = \tan\ 88.63° = 41.814$$

The angle between the horizontal plane and the reflected vector (reflection elevation angle) is given by

$$\tan\theta_r = \frac{C_r}{\sqrt{A_r^2 + B_r^2}}$$

Fig. 14 shows the hourly evolution of the above functions for a sample day (March, $2^{nd}$)

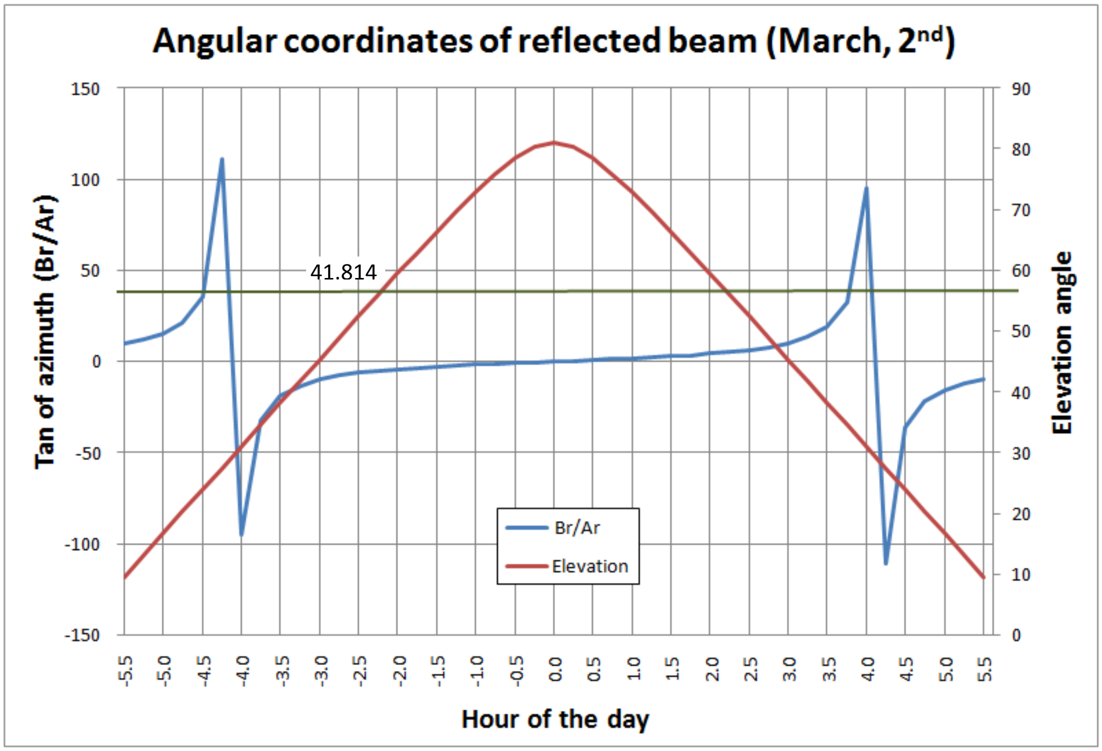
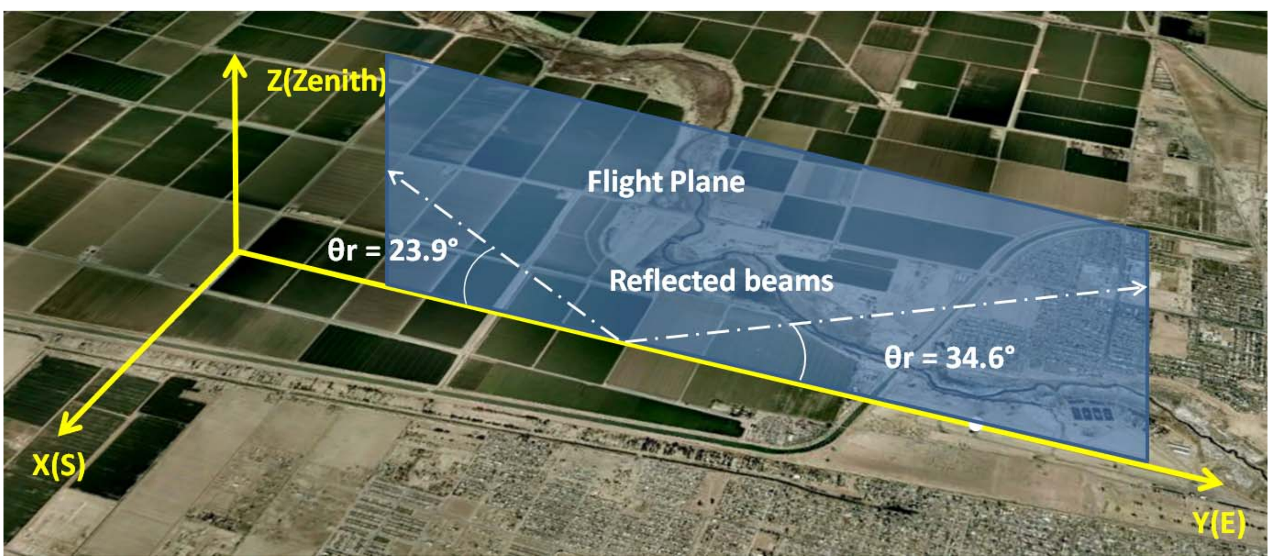



*Fig 14.- Angular coordinates of reflected beam (March, 2nd)*

It can be seen that the reflected beam will be contained in the flight plane at 07:30h (after sunrise) and at 15:45h (before sunset). The reflected beam will be pointing upwards with an angle of 23.9° and 34.6° respectively.



Obviously, the reflection held at 07:30 would affect airplanes landing Calexico from West, while the reflection held at 15:45h would afect airplanes landing or launching from East. In both cases, a long-term glint exposure would only occur if the airplanes were landing at the same particular angles (i.e., 23.9° and 34.6° respectively). It should be noted that normal landing angles are within the range of 3° and 6°, so in this particular day no risk of prolonged glint is possible.

The same procedure is repeated for all days in a year. Results in Fig.15 shows the elevation angle of the reflected beam in function of the day, whenever the in-plane condition occurs. Bandwith between estimated minimum and maximum airplane landing angles (3° and 6°) is superimposed :

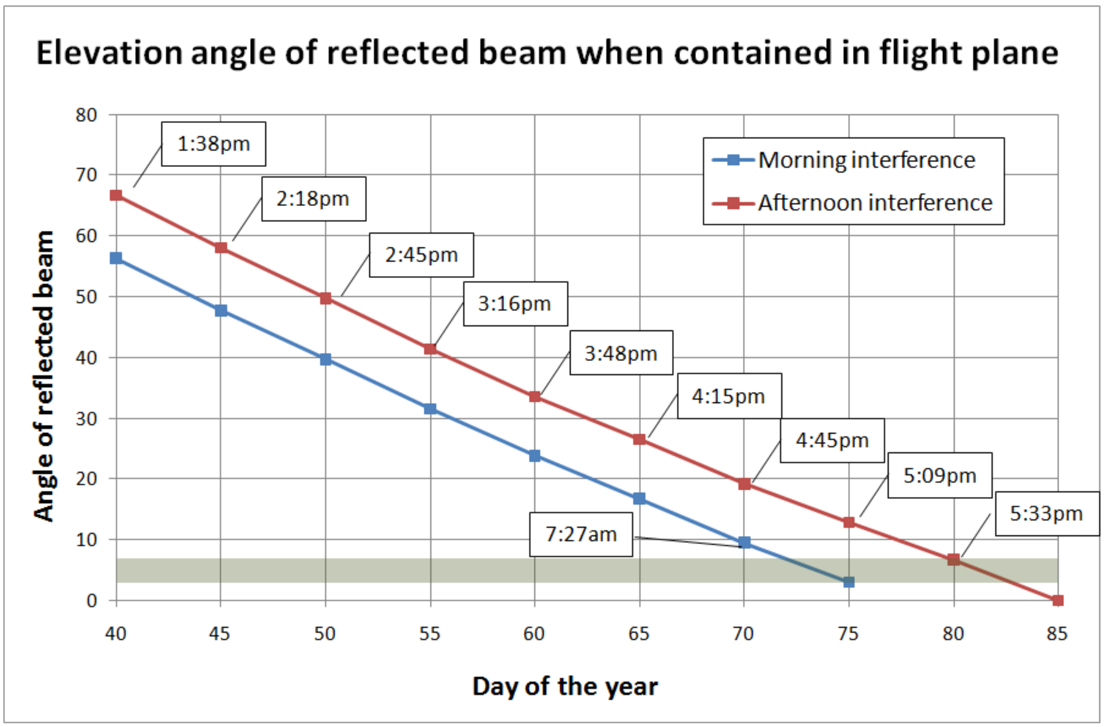



*Fig 15.- Reflected beam elevation angle and landing angles – Runway 29*

There are a few days in the year where there is an eventual risk of glint from the PV modules to landing airplanes. These particular days are 72 to 75 (2nd week of March - morning time) and 80 to 83 (3rd week of March - evening time). Because of yearly simmetry, the same occurs in mid-October.

Fig. 16 shows sun coordinates for a typical day in these periods (day 73). Interference with landing path occurs at around 07:37 hours, sun azimuth is -84° and elevation only 3°. Therefore airplanes reaching Calexico airport runway from the West end will have the sun disc just in front of them. It is considered that glint effect is neglegible when compared to direct sun light exposure, as in this case.

Similarly, planes landing or launching from the East at day (say) 82, will be facing the sun disc at sunset, and again the risk of glint is negligible when compared to the light intensity of direct sun.

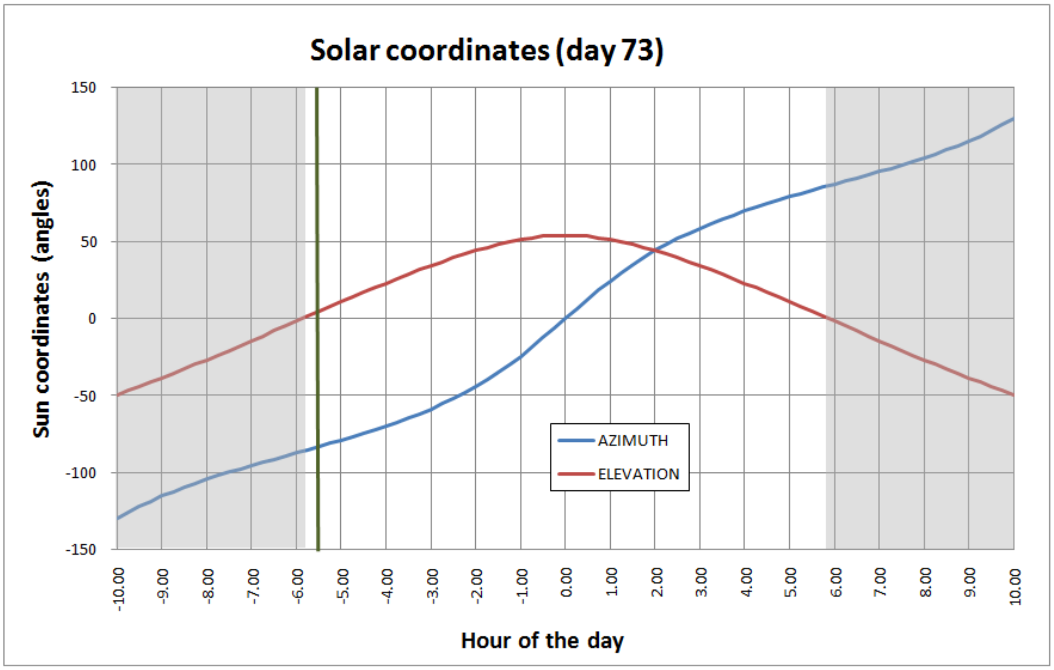
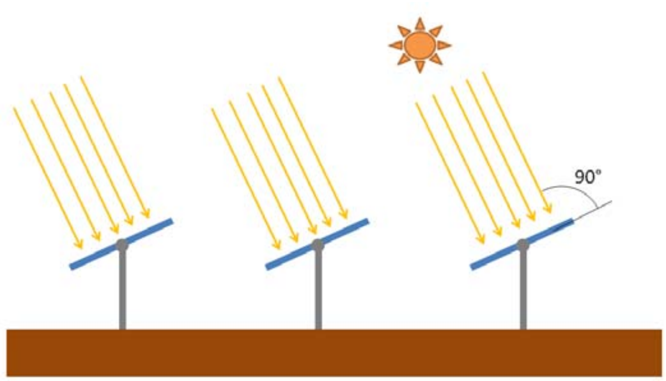



*Fig 16.- Sun postion for selected typical interference day – Green vertical line shows time of interference with airplane landing path.*

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.



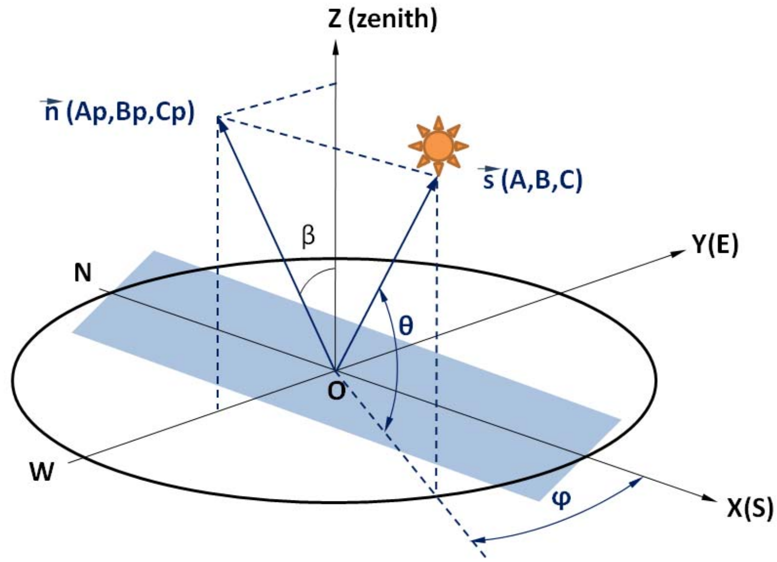



*Fig 17.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

this can be written as

$$\cos\gamma = -B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\,(\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad\qquad \tan\beta = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

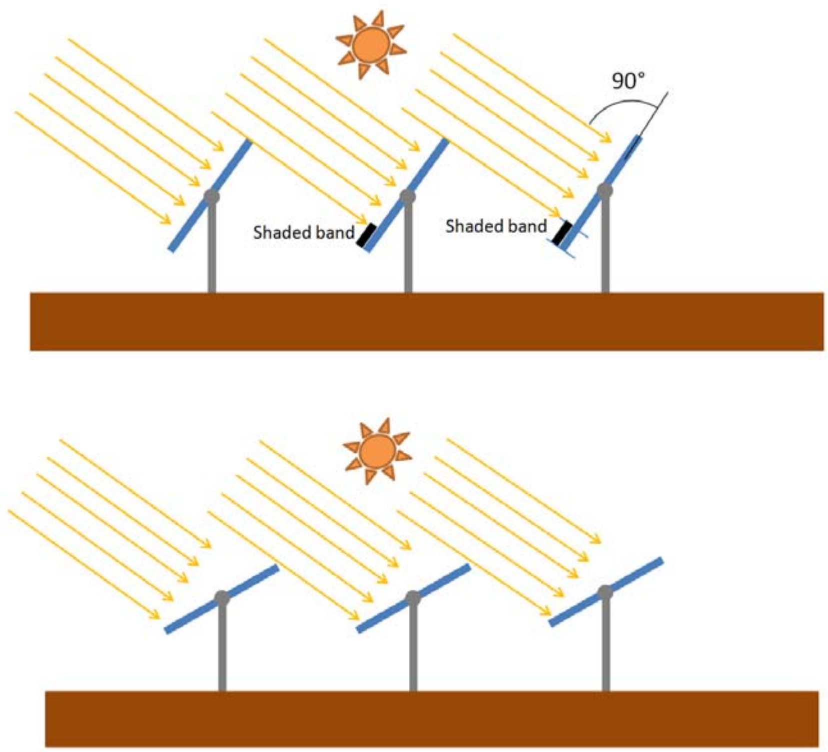



*Fig 18.- Above: Mutual shading without backtracking.*
*Below: Backtracking corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons.

Fig. 19 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

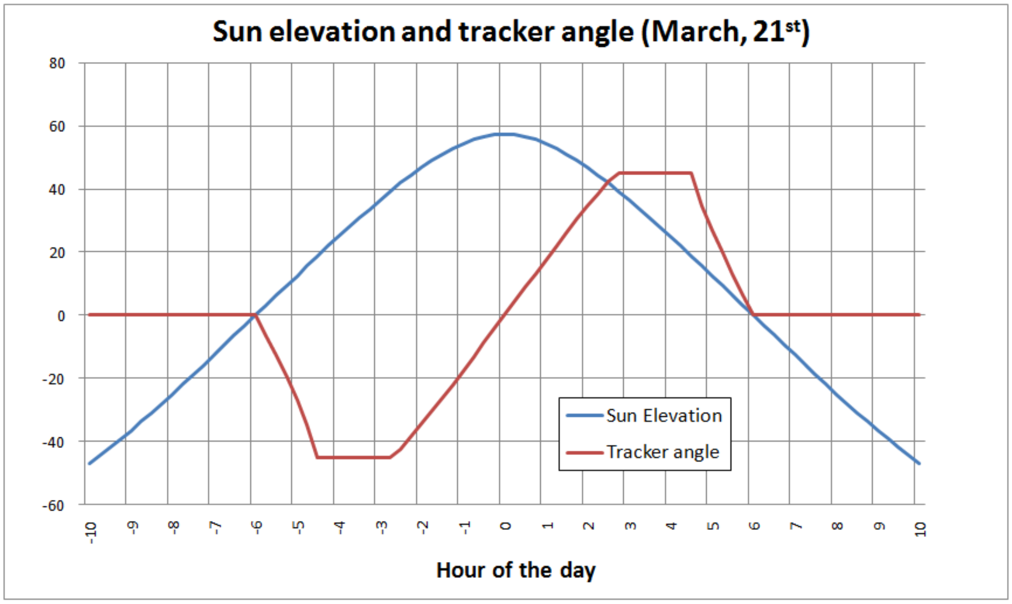



*Fig 19.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 20,

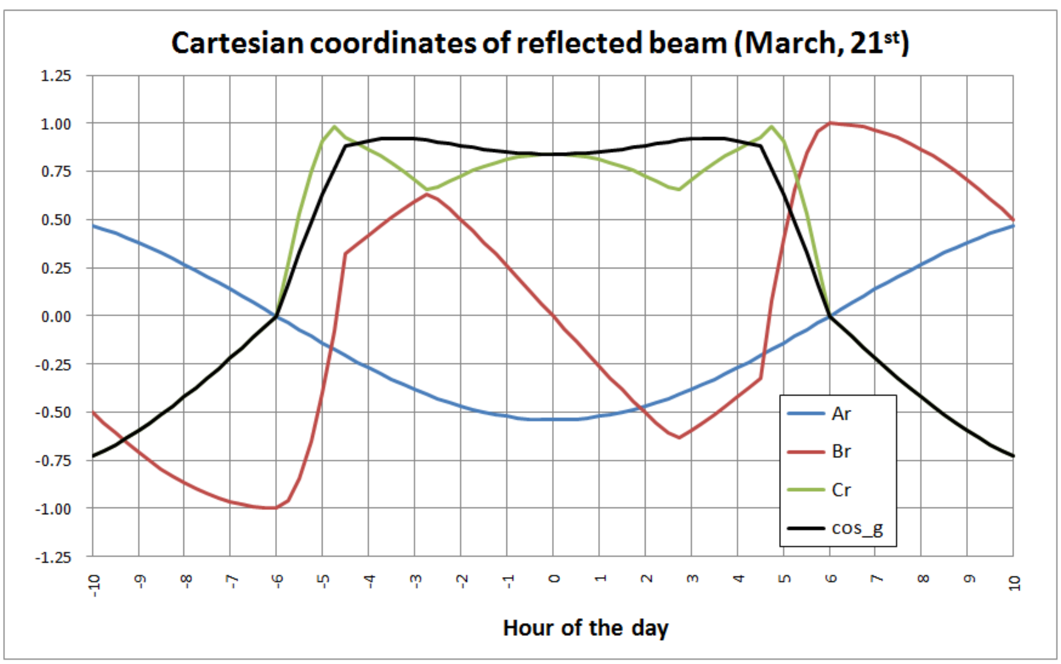



*Fig 20.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at Calexico

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

As an example, Fig. 21 shows the azimuth and elevation angle of the reflected beam. The green line defines the flight-plane azimuth condition for Calexico, thus the reflected beam will be contained in this particular plane at 8:45am and 3:00pm, but in both cases the beam elevation angle is well over 40°, so there is no risk for glint.

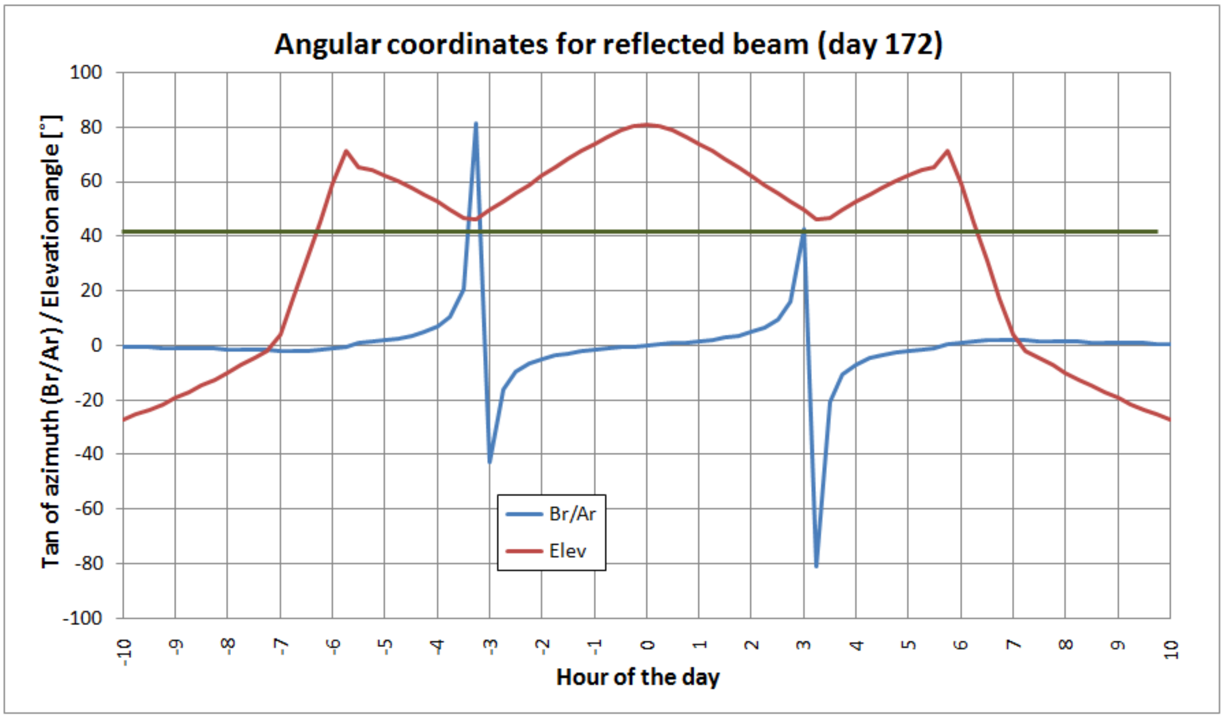



*Fig 21.- Angular coordinates for reflected beam (day 172)*

The same calculation is repeated for a complete year and results shown in Fig. 22.

It can be seen that whenever the reflected beam is contained in the flight-plane, its elevation angle is very far from the usual approaching or launching angles to the airport, so there is no risk of glint with trackers.

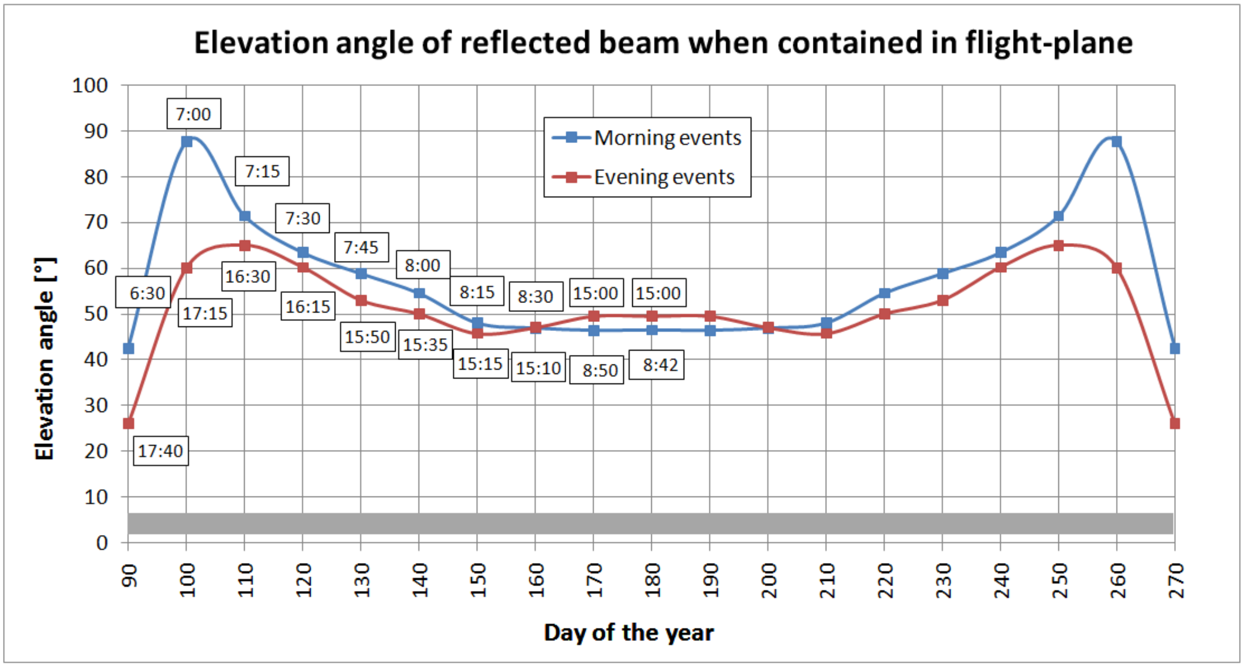



*Fig 21.- One year results for elevation angles of reflected beam when contained in the flight plane. For the six month period from October to March the reflected beam is never contained in the flight-plane.*

# 4 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected, but this might produce some glint to KVPs. For this Project, it is considered that airplanes landing at or taking-off from Calexico airport might be exposed to glint.

To determine the glint risk, a geometric analysis is done for both scenarios: Fixed tilt PV modules and Horizontal Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes (that is 35040 points). All mathematical expressions hereby described are implemented in a computer routine.

In the case of fixed tilt PV fields it has been demonstrated that, in the few cases when there is some risk of glint by PV modules, the airplane will also be directly facing the sun disk, so it can be concluded that glint from PV modules will not have any relevant effect on airplanes' visibility, nor deteriorate the actual approaching or launching flight conditions.

If the PV plant is built with horizontal axis tracking technology, the eventual reflected beam would have a high elevation angle (that is, pointing upwards), so no interference with approaching or launching airplanes from Calexico airport will ever occur.

The same conclusions can be extended to other tracking technologies (single inclined axis or double axis trackers). With these devices, the tracking efficiency is higher than with horizontal axis trackers, therefore the incident angle is even lower, and the reflected beam will be pointing the sun disk more closely. Risk for glint when landing of launching might theoretically occur only at low sun elevation angles (i.e., sunrise or sunset); however, during these particular hours the backtracking technology modifies the tracking algorithm to avoid mutual shading thus re-orientating the reflected beams upwards, far from the flight path.

It is concluded that this Project will not have any relevant glint effect for airplanes landing at or taking-off from Calexico airport. This is also applicable regardless of whether the Project is built in one, two or more phases.

# APPENDIX H

Visualization Study

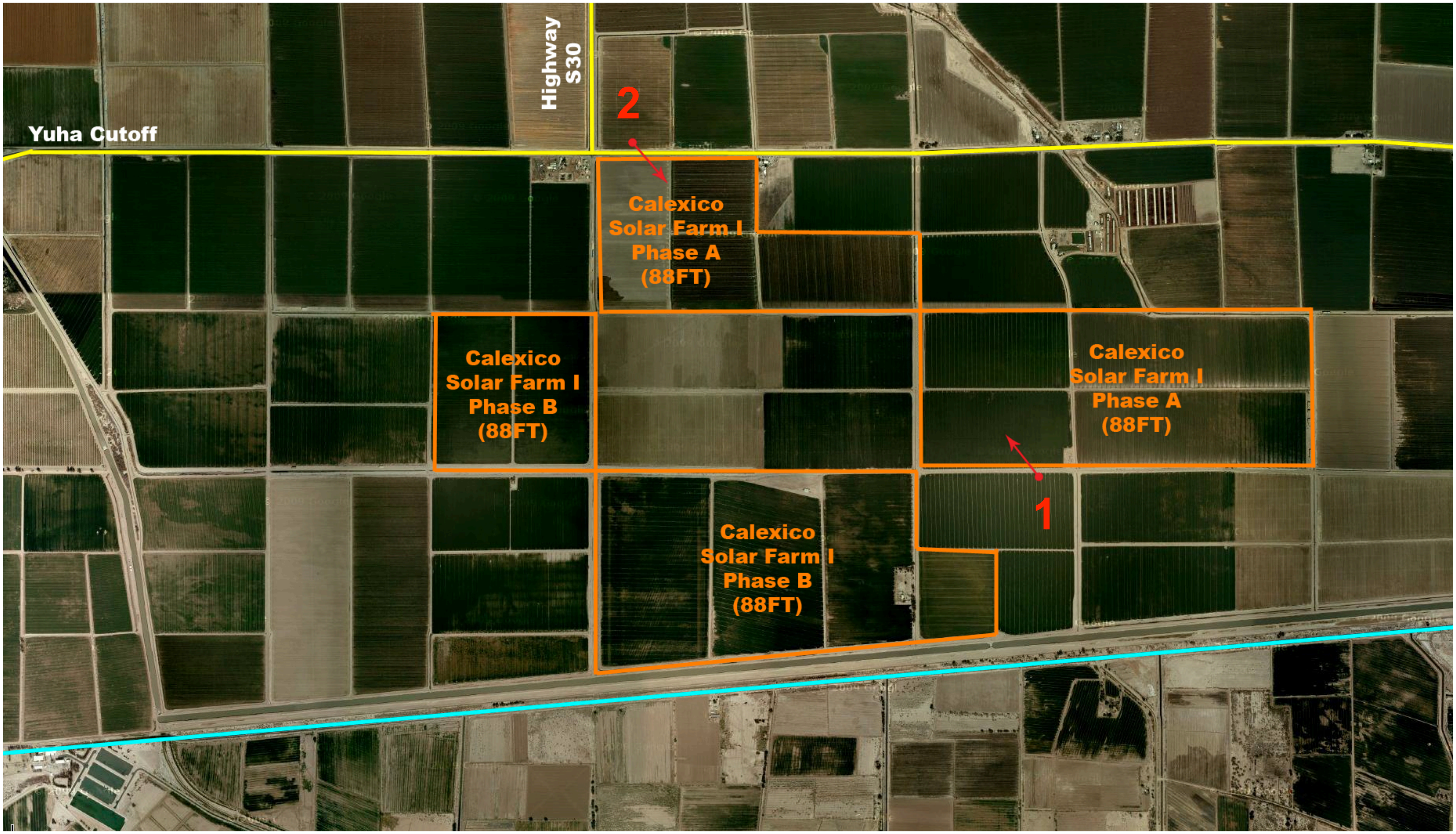
# Visualization Study

# Calexico Solar Farm I

Visualizations by

modative

Design
Develop
Build




Final design and location/route may be revised prior to issuance of permits

Viewshed Locations

**Calexico Solar Farm I (88FT)**

Key Plan

**date:** 7/15/11
**project:** 88FT

KEY

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Anza Road

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT

Existing

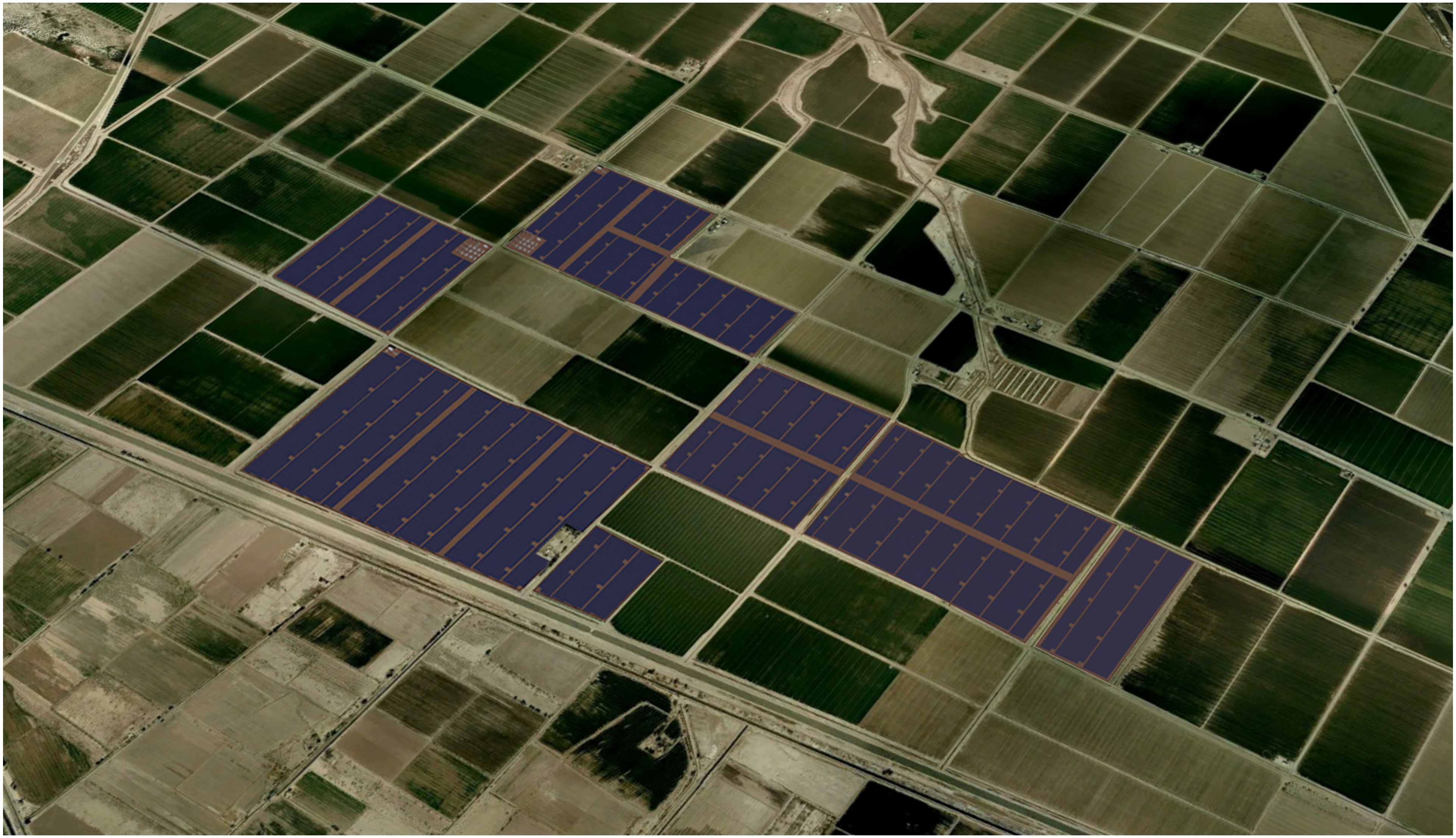
Proposed

Final design and location/route may be revised prior to issuance of permits

Looking South-East Along Highway 98

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT



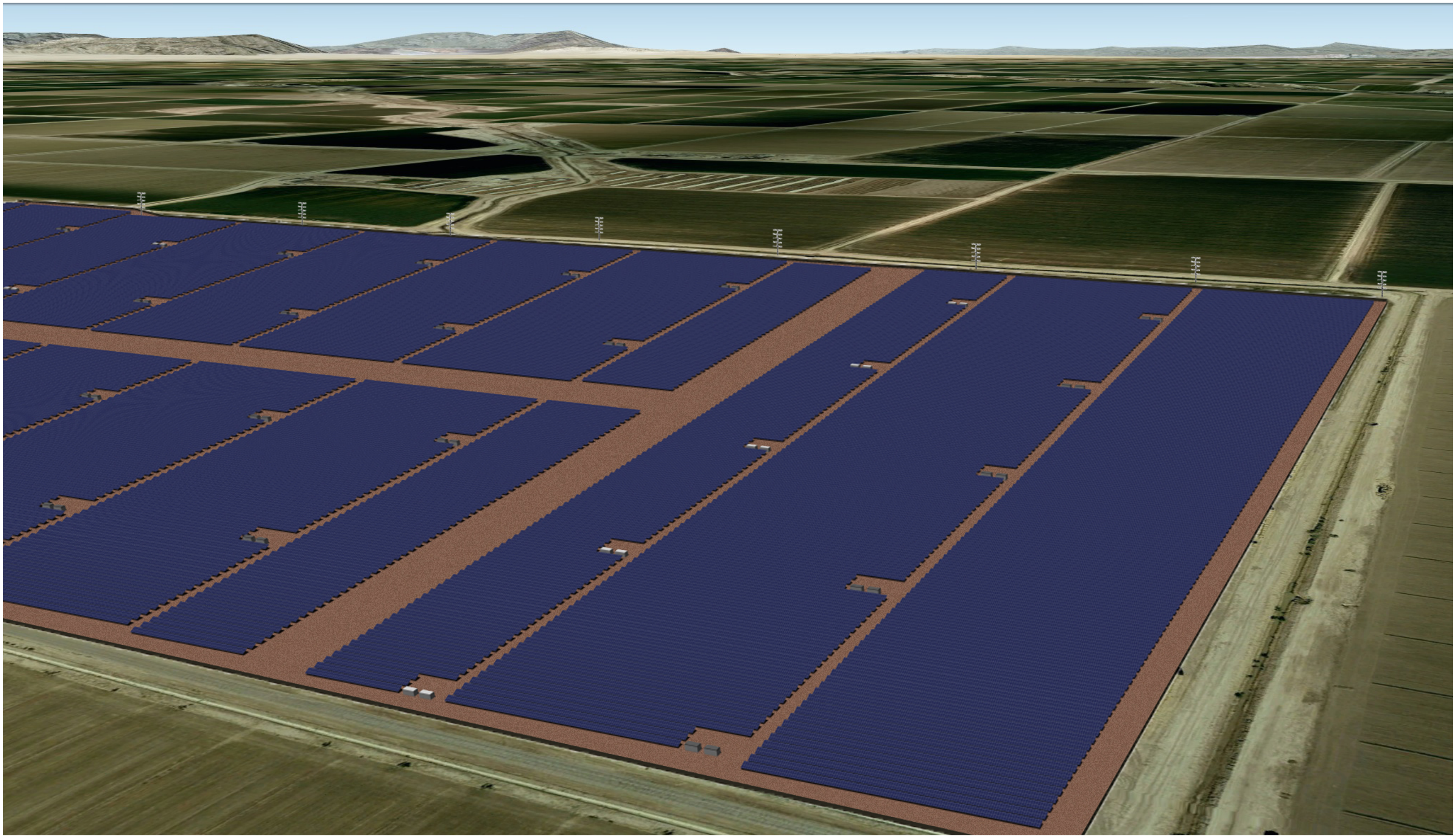
Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT



Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT

# APPENDIX F

## Glare Analysis for Ground Traffic

April 11, 2011

Good Company
65 Centennial Loop, Suite B
Eugene, Oregon 97401

Mr. Thomas Buttgenbach
88FT 8ME LLC
10100 Santa Monica Blvd, Suite 300
Los Angeles, CA 90067

Dear Mr. Thomas Buttgenbach:

The purpose of this technical memo is to augment the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report. *The Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report analyzed the 88FT project as being constructed in one phase and under one conditional use permit. However after completing the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report, the project's construction plan was modified to reflect a second conditional use permit that would allow the project to be constructed in more than one phase. We have reviewed and analyzed this modification and have determined that the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report remain unchanged. In other words, the development of the project in more than one phase or CUP does not change the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm I* report. Please call me if you have any questions.

Joshua Skov

Principal, Good Company

## Potential Impacts from Reflection of Proposed Calexico Solar Farm I

Draft Date: July 8, 2011

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### KEY FINDINGS

- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection above the built environment and nearby traffic corridors.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Calexico Solar Farm I, which is located 5 miles west of Calexico in Imperial County, California. The project site is comprised of seven parcels of land with a total area of 1,333 acres. See Appendix A for aerial photographs of the site.

The proposed project is a ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the proposed Calexico Solar Farm I on nearby roads, buildings. The reflection impacts on aircraft using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

### Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules. Photovoltaic panels are using the absorbed energy in two ways; 1) the panels generate electricity, and 2) the mass of the panels heat up.

In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

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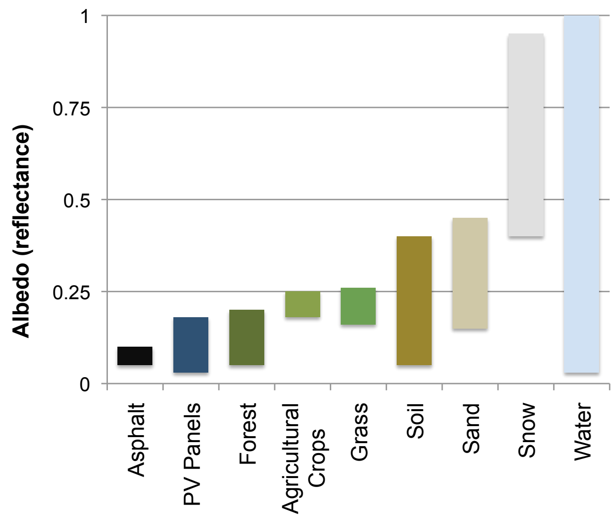
[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.
[2] Ibid.

## Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around 0.10.[3] By comparison, sand has an albedo between 0.15 and 0.45 and agricultural vegetation has an albedo between 0.18 and 0.25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

**Figure 1:** Albedo comparison for various surfaces.




## Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

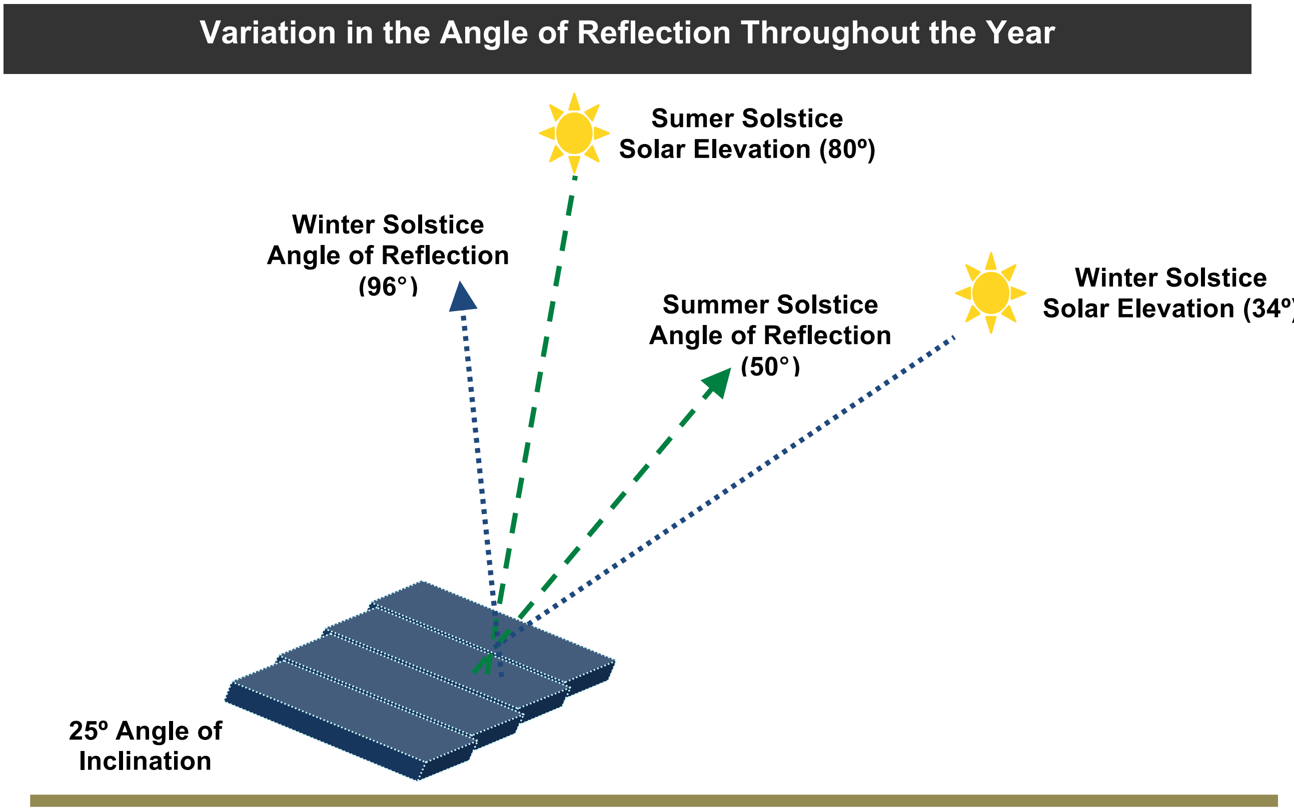
The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs midday on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 2 below). The potential impact at that moment is the best proxy for maximum impact overall.

During summer solstice at the proposed project's latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is unlikely that any objects in the built environment near the project site would be adversely affected by a direct reflection of sunlight from this angle, including vehicles traveling on nearby roads or houses south of the project site.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed project's latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.39 degrees north.

Figure 2: The range of the sun's angle-of-reflection depending on the time of year.




The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 20 feet (the approximate distance from the southern edge of the Calexico Solar Farm I project, array sections Parcel II and Parcel III, to the edge of Anza Road), the height of the reflected sunlight from the array would be nearly 24 feet in elevation, well above the California truck height limit of 14 feet. It's important to note that Anza Road and other roads in the immediate vicinity of the proposed arrays are not major transportation corridors and as such are not expected to support significant passenger or commercial traffic. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project, further obscuring the peripheral view of the project (and any indirect reflection).

There is a house located south of the Calexico Solar Farm I, below the Parcel II arrays. The house is 250 feet south of the proposed arrays. At this distance, the height of direct reflection is 298 feet, the height of a 20-story building[6].

[6] This number of floors assumes a height of 15 feet per floor.

**Figure 3:** Map of the points listed in Figure 4 and the "on the ground" distance from each point to the array.

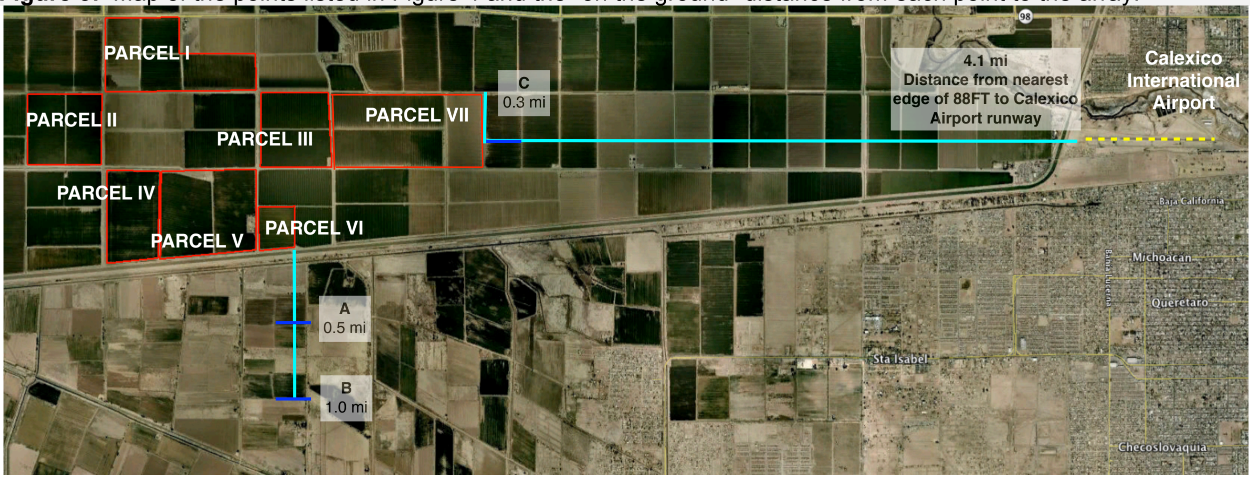



**Figure 4:** Elevation of direct reflection for the points shown on Figure 3.

| Point on Figure 3 | Elevation of Direct Reflection | |
|---|---|---|
| | miles | feet |
| A | 0.60 | 3,147 |
| B | 1.19 | 6,294 |
| C | 0.36 | 1,890 |

## Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[7]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[8]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project.

## Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array the greatest potential for a low angle of reflection, that might impact the built environment, occurs midday on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At midday on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

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[7] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see "Panache Valley Solar Farm Project Glint and Glare Study" (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and "Topaz Solar Farm Reflection Study" (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).

[8] TrinaSolar. "Reflection Coefficient of Trina Solar Modules." Personal communication with Thomas Houghton, June 30, 2010.

## Appendix A: Glare Analysis Explanation

### Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[9] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

**Figure 7:** Angle of direct reflection on summer solstice (June 21).

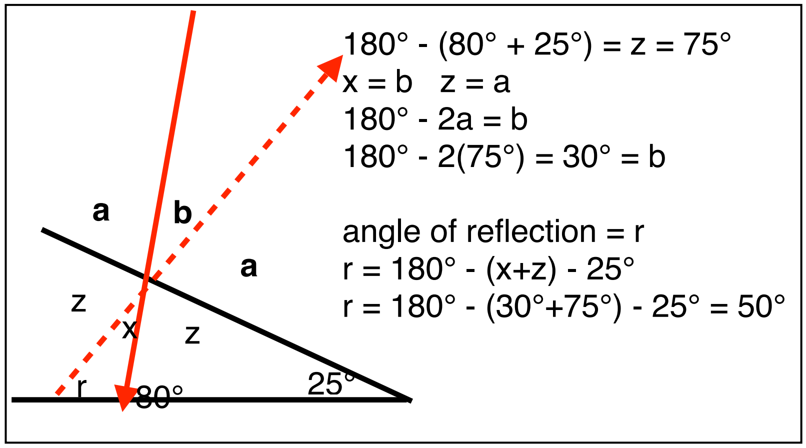
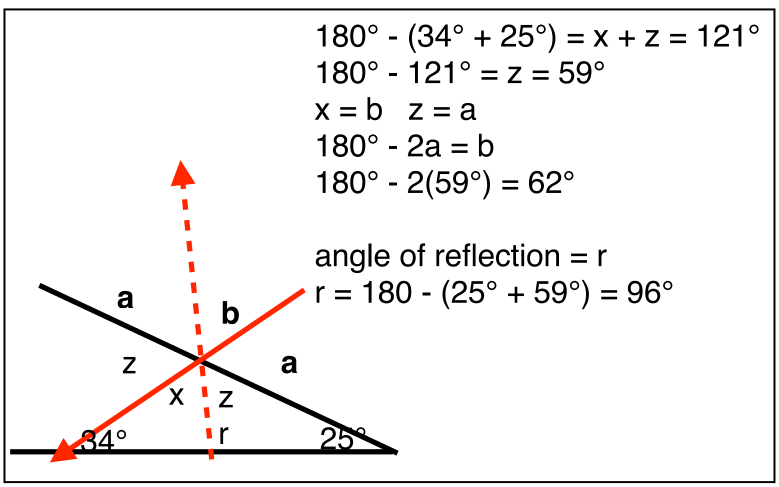



Figure 7 to the right depicts this reflection. All angles within a triangle summed equal 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

**Figure 8:** Angle of direct reflection on winter solstice (Dec. 21).



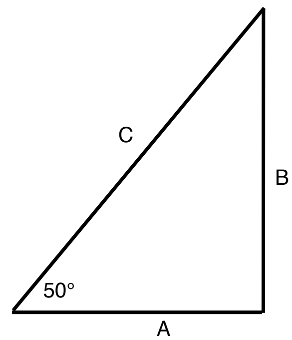

Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point during winter solstice on December 21st (see Figure 8, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[9] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

## Determining the Height of Reflection

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Calexico Solar Farm I. Figure 9 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

**Figure 9:** Calculation to determine direct reflection.

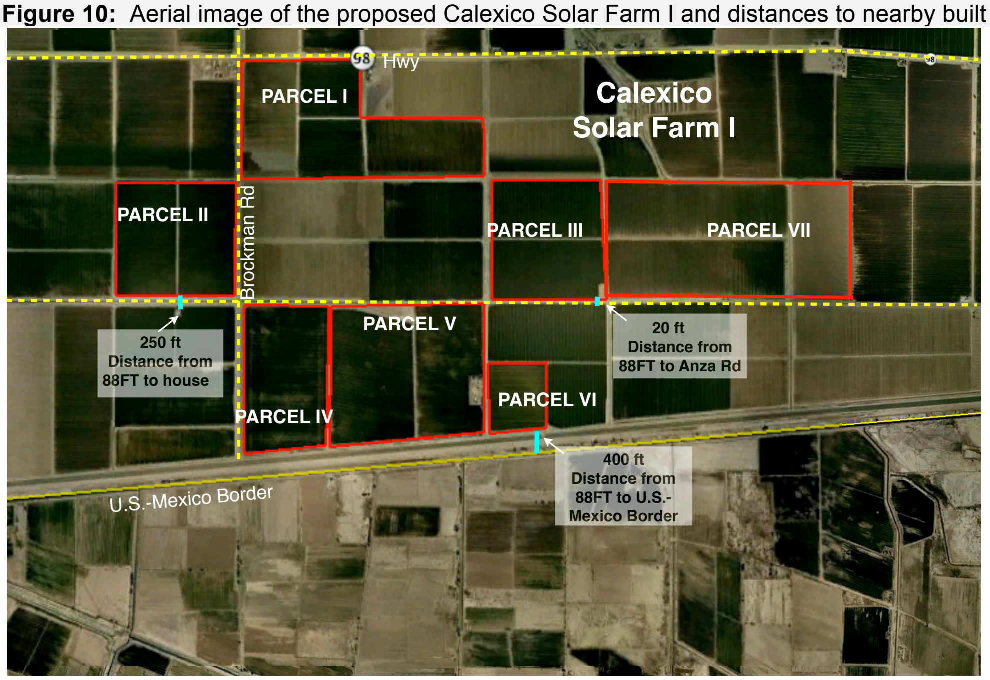



$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 10 is an aerial picture of the sited Calexico Solar Farm I from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico Border (yellow line) as well as the four portions of the project which serve as the boundaries for the panel arrays in this project. Figure 10 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 10 describe the height of the direct reflection at the various distances shown by the blue lines.

**Figure 10:** Aerial image of the proposed Calexico Solar Farm I and distances to nearby built structures and roads.

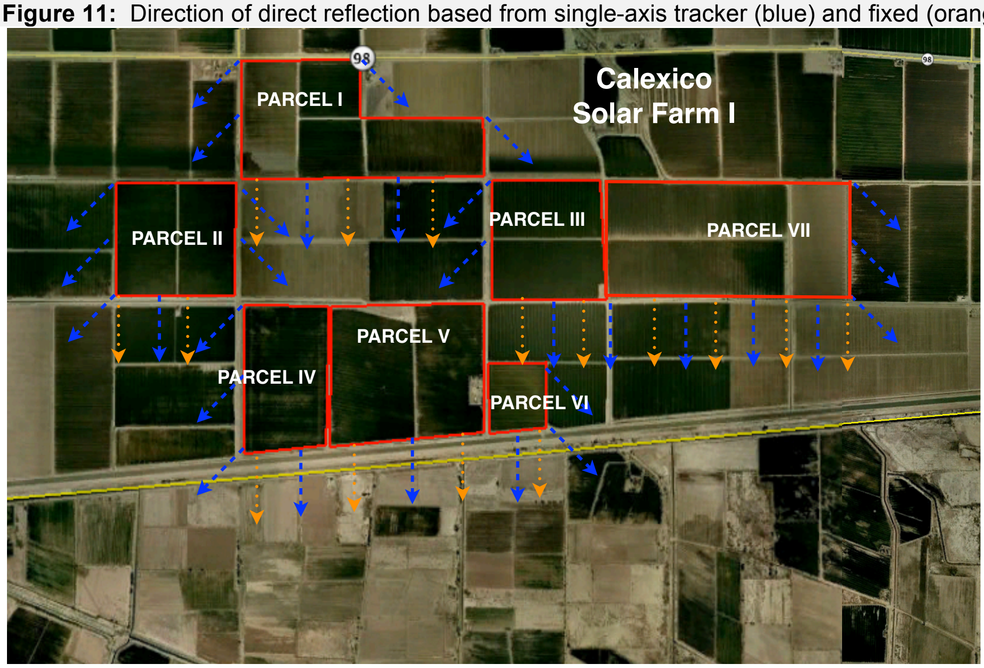



- At 20 feet from the solar panels the height of the reflection is already at 24 feet.
- At 250 feet from the solar panels the height of the reflection is 298 feet or higher.
- At 400 feet from the solar panels the height of the reflection is 477 feet or higher.
- See the Reflectivity Analysis conducted by Aztec Engineering for details on potential impacts to aircraft utilizing Calexico International Airport.

## Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

**Figure 11:** Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).



# APPENDIX G

## Glare Analysis for Air Traffic

# CALEXICO Solar Farm I (88FT 8ME, LCC)

# REFLECTIVITY ANALYSIS

REVISION INDEX

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# Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to a series of photovoltaic (PV) power plants being developed by 88FT 8ME, LLC. Project location is nearby the Calexico airport in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the corresponding airport runway if reflected sun light beam intersects the approaching flight path.

Fig. 1 shows the location of the future PV plant relative to Calexico airport.

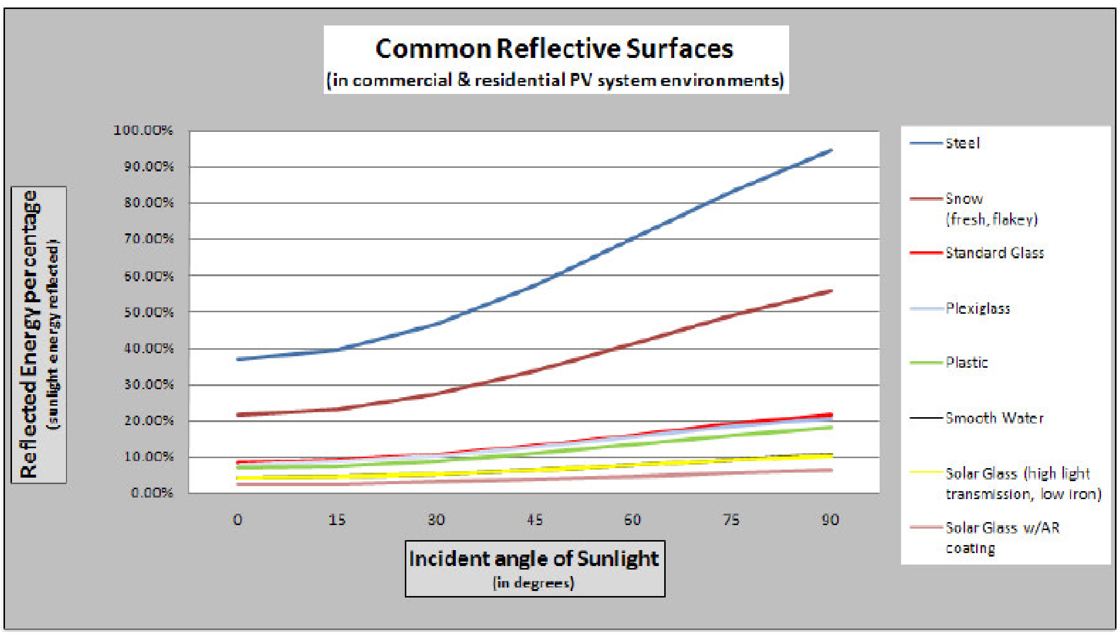

*Fig 1.- Location of PV Project and Calexico airport*

To evaluate the risk of direct sun light reflection events a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer direct reflection.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of the study:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the

reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and have negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules, for instance agricultural environment has higher Glare effect than PV modules.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to the airport runway.

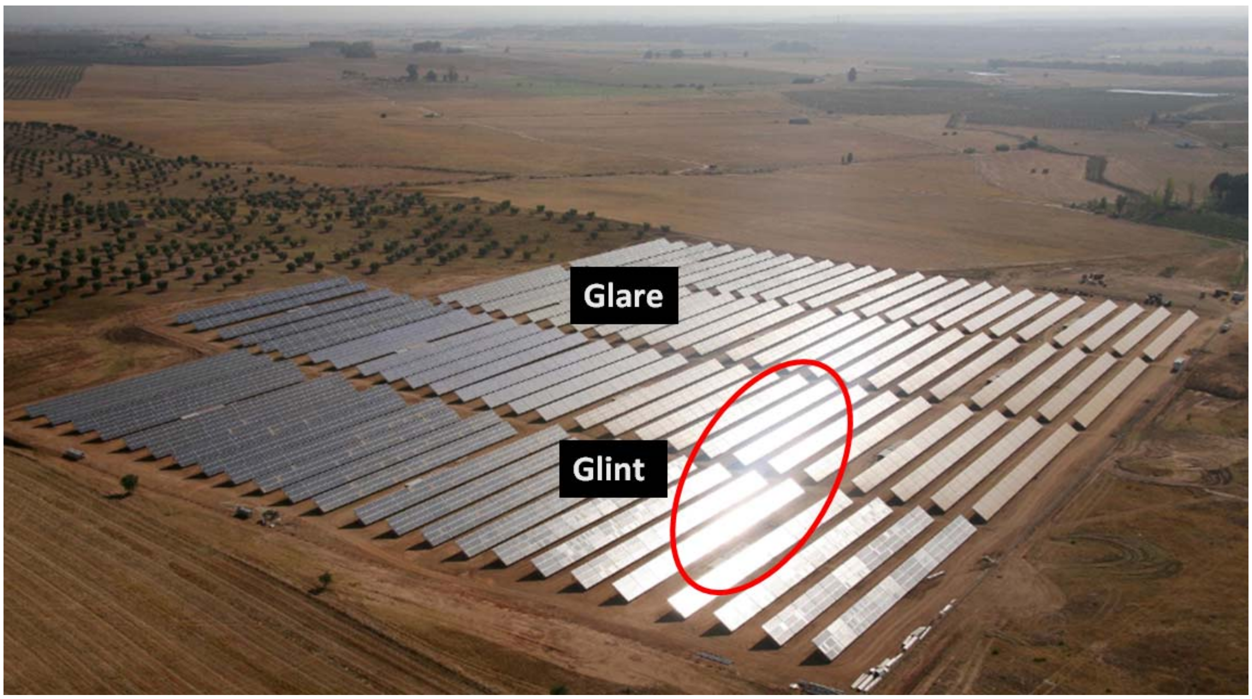



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Mathematical analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the future PV plant location, as shown in Fig. 3 below:


*Fig 3 .- Reference coordinate system*

Next image shows a 3D rendering of the future project

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

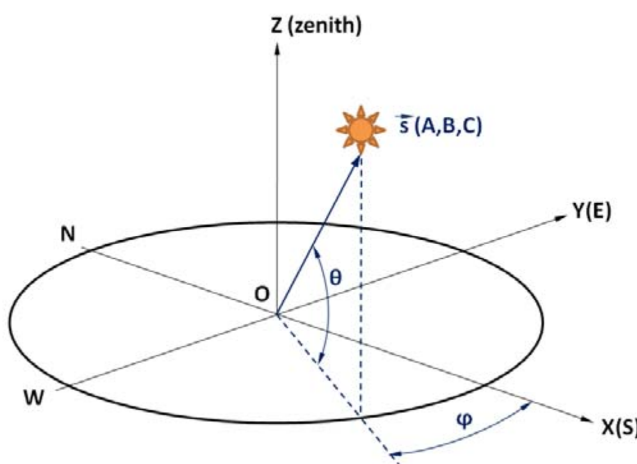



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta \ \cos\varphi$$
$$B = -\cos\theta \ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:
Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32,... until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; ... etc).
As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in the next graph:

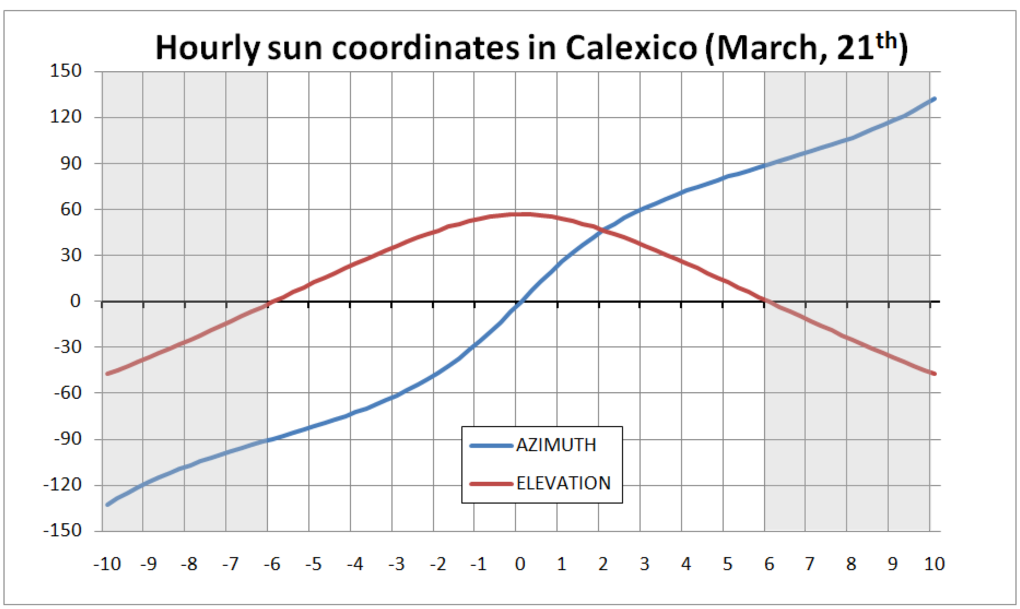



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

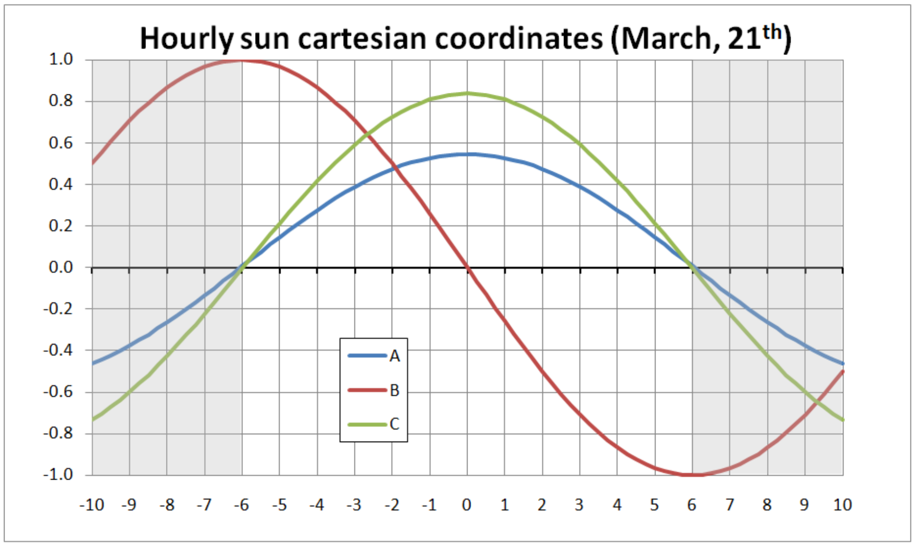



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located at the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

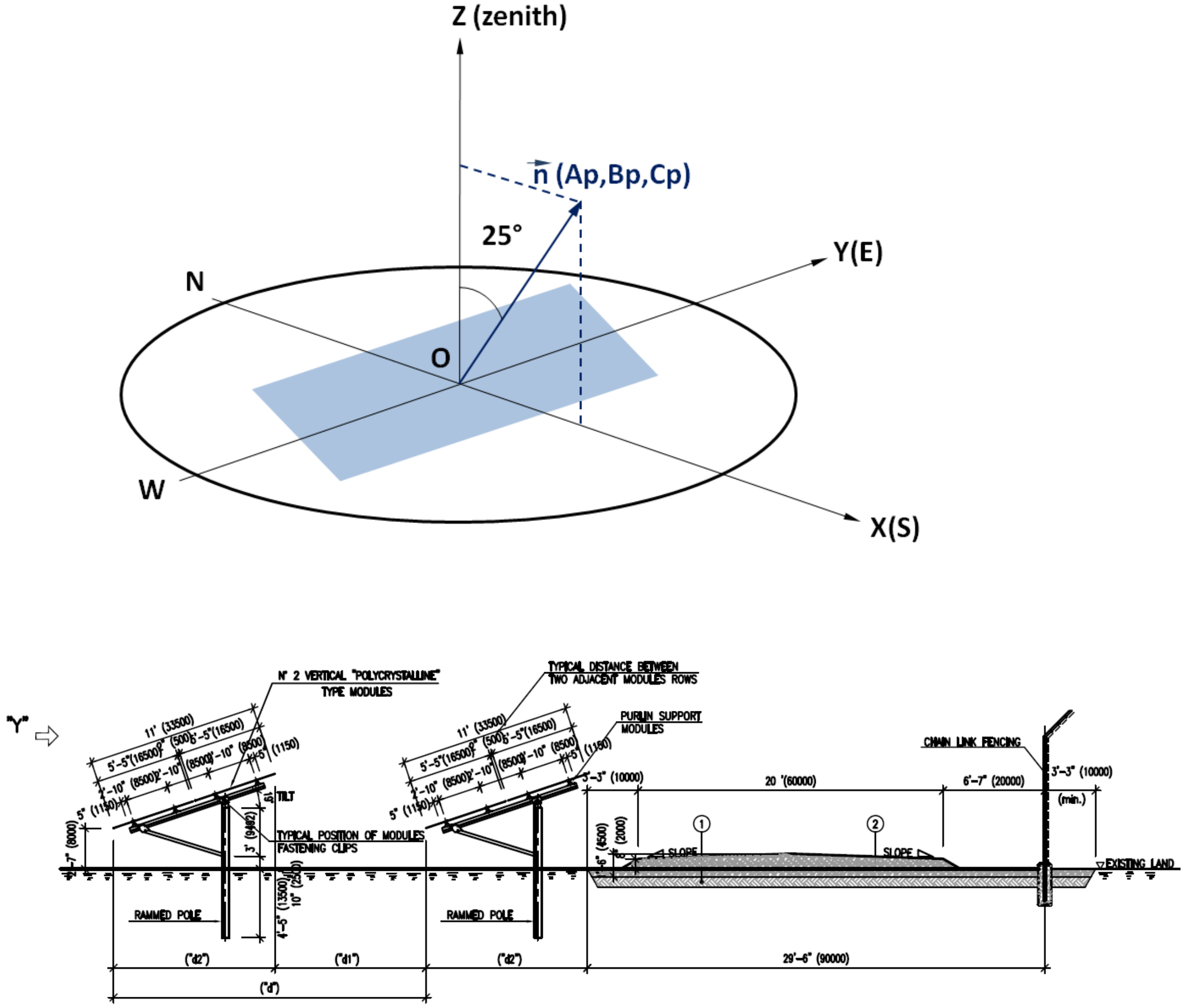



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:

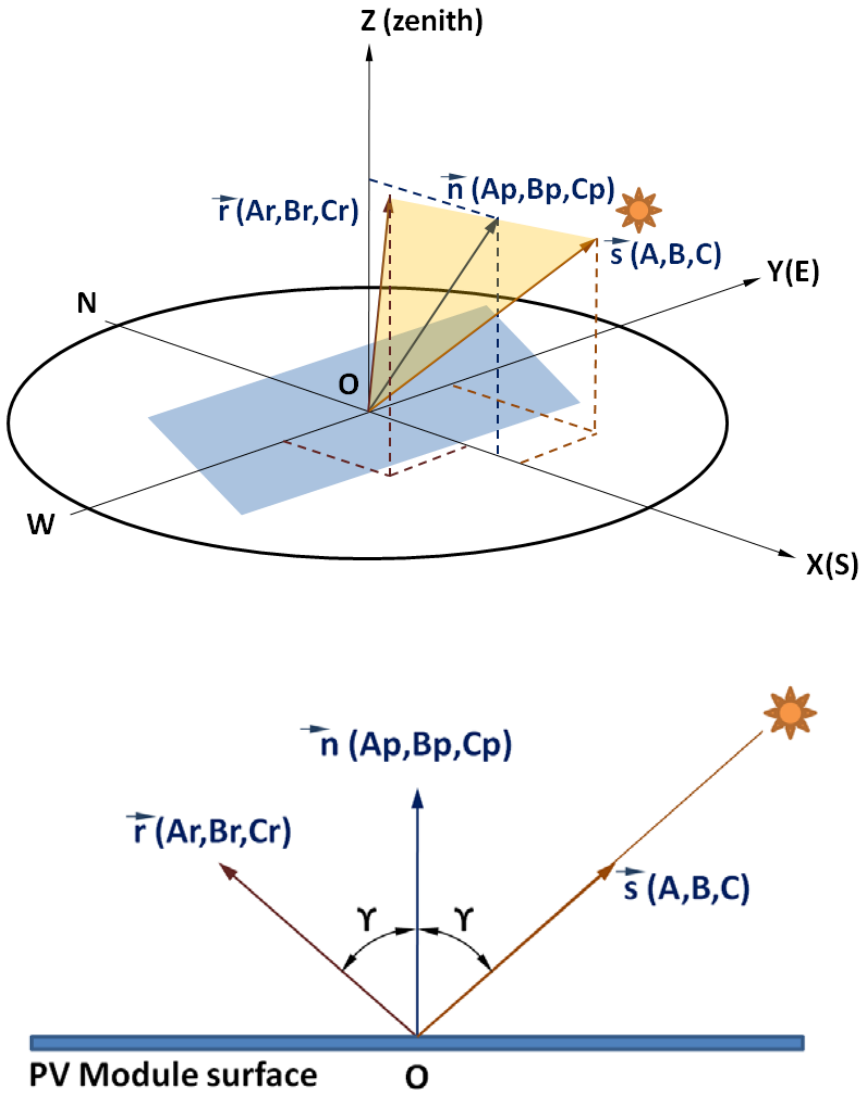



*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + \,C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\,\vec{n} - \vec{s}$$

and its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\, A_p - A$$
$$B_r = 2\ \cos\gamma\, B_p - B$$
$$C_r = 2\ \cos\gamma\, C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

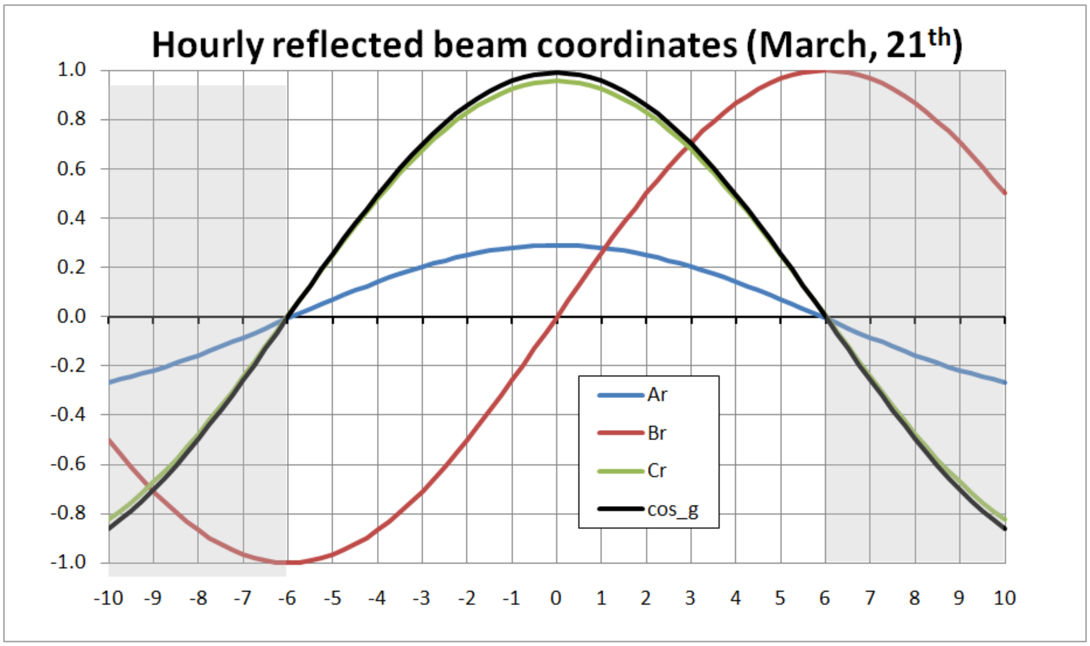



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity at Calexico runway (fixed systems)

To define the location of relevant KVP it is hereby assumed that the approaching airplane follows a straight line contained in a vertical plane (the "flight plane") that also contains the runway axis (Fig. 10).

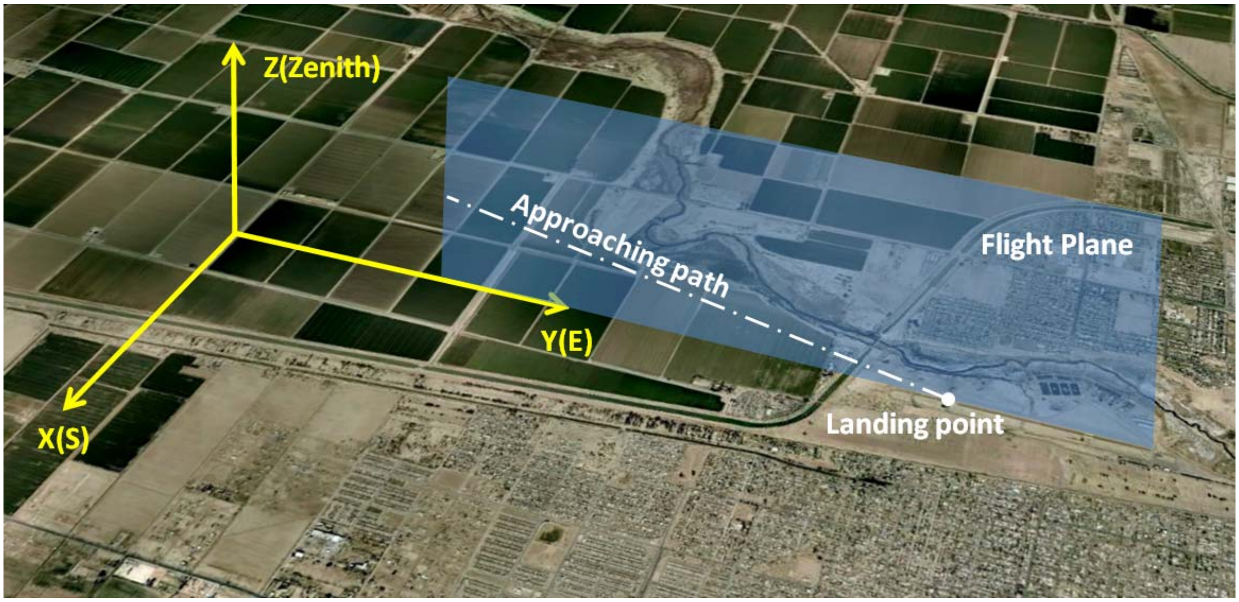



*Fig 10.- Geometry of approaching path*

The vertical flight plane, containing the approaching path, is defined by the following equation in the reference Cartesian axis system:

$$\Pi \equiv 0.9997\ x - 0.0239\ y = 0$$

The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

Runway azimut is 88.63°. Cartesian coordinates for any reflected beam r = (Ar, Br, Cr), if contained in the flight plane, shall satisfy the following condition (beam azimuth):

$$\frac{B_r}{A_r} = \tan\ 88.63° = 41.814$$

The angle between the horizontal plane and the reflected vector (reflection elevation angle) is given by

$$\tan\theta_r = \frac{C_r}{\sqrt{A_r^2 + B_r^2}}$$

Fig. 14 shows the hourly evolution of the above functions for a sample day (March, 2$^{nd}$)

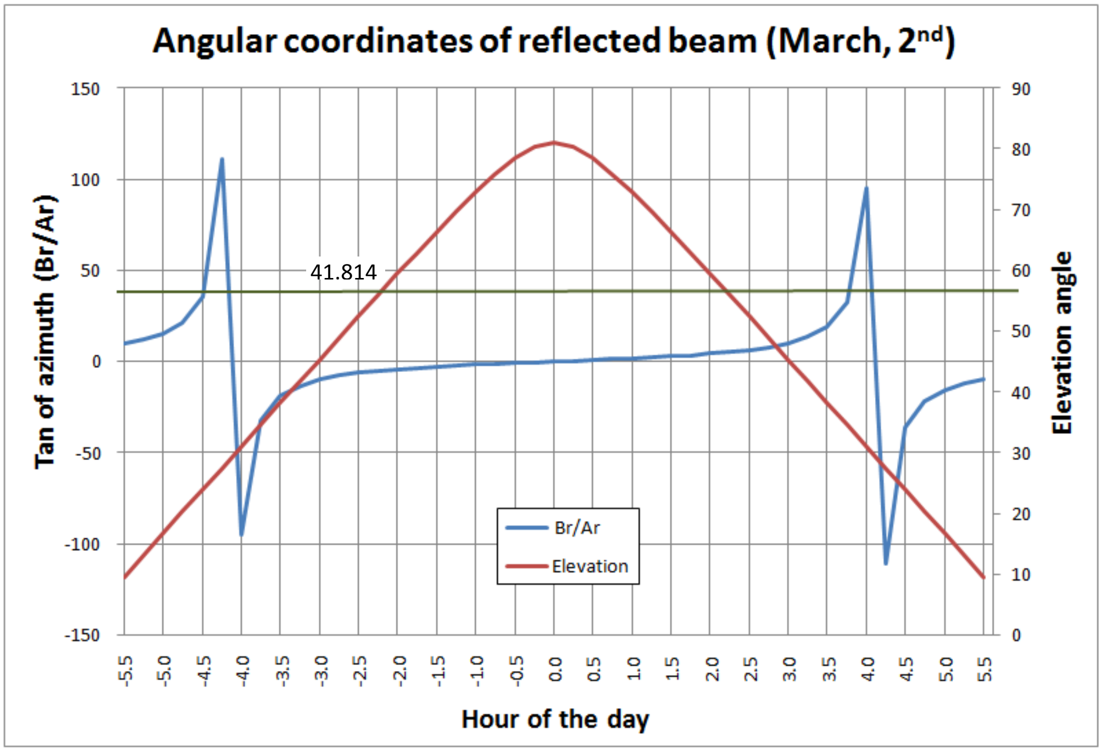
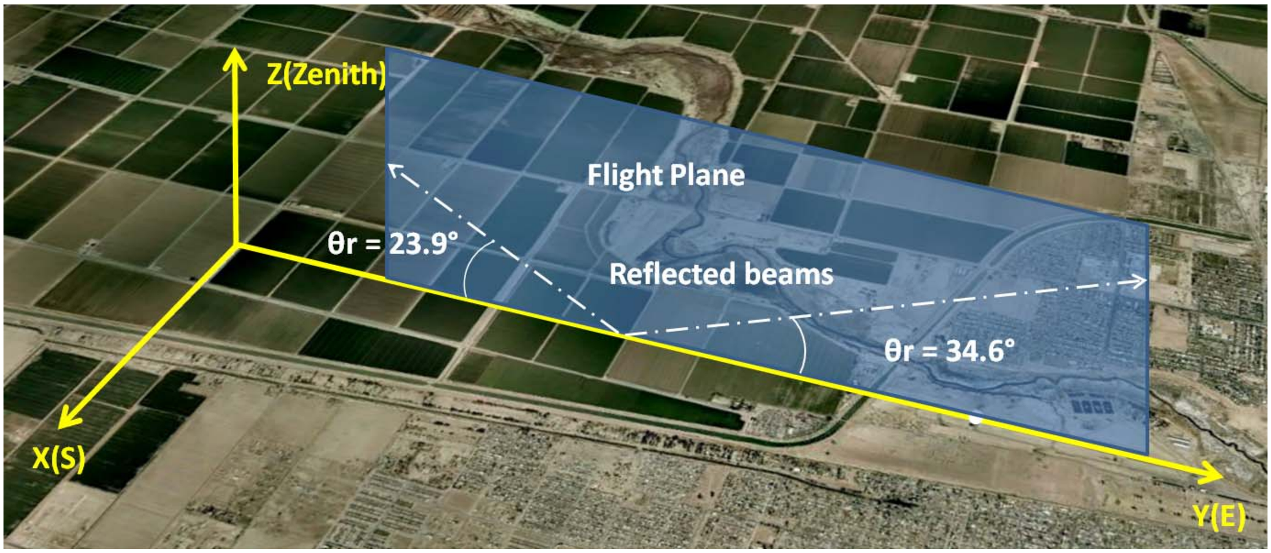



*Fig 14.- Angular coordinates of reflected beam (March, 2nd)*

It can be seen that the reflected beam will be contained in the flight plane at 07:30h (after sunrise) and at 15:45h (before sunset). The reflected beam will be pointing upwards with an angle of 23.9° and 34.6° respectively.



Obviously, the reflection held at 07:30 would affect airplanes landing Calexico from West, while the reflection held at 15:45h would afect airplanes landing or launching from East. In both cases, a long-term glint exposure would only occur if the airplanes were landing at the same particular angles (i.e., 23.9° and 34.6° respectively). It should be noted that normal landing angles are within the range of 3° and 6°, so in this particular day no risk of prolonged glint is possible.

The same procedure is repeated for all days in a year. Results in Fig.15 shows the elevation angle of the reflected beam in function of the day, whenever the in-plane condition occurs. Bandwith between estimated minimum and maximum airplane landing angles (3° and 6°) is superimposed :

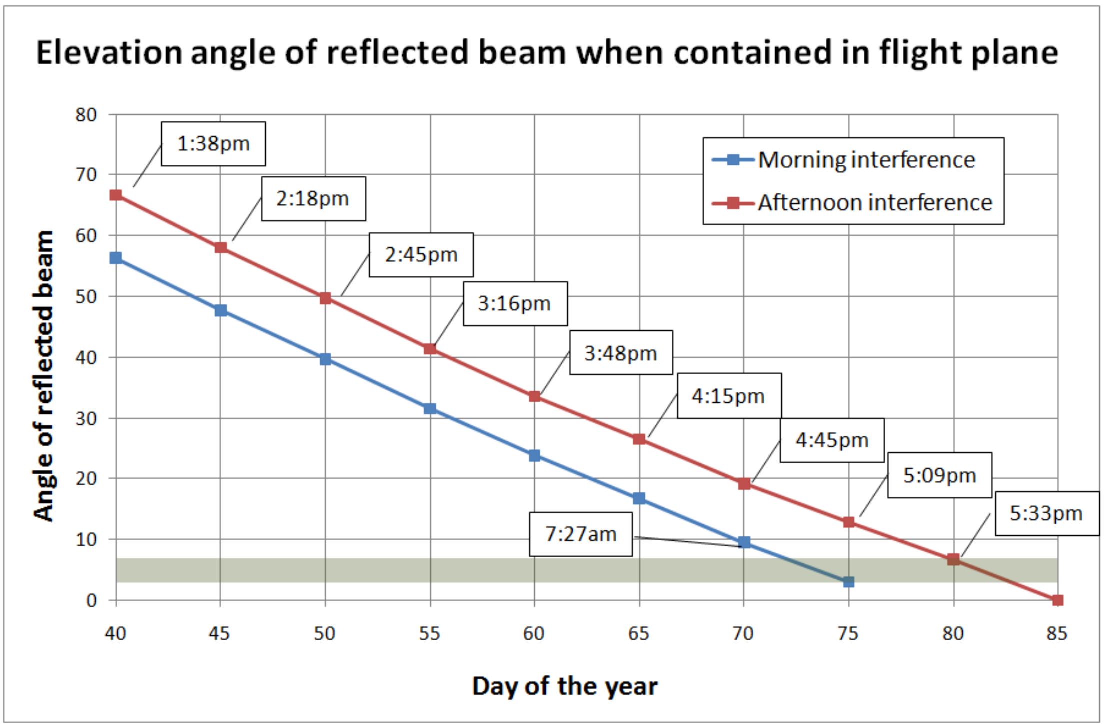



*Fig 15.- Reflected beam elevation angle and landing angles – Runway 29*

There are a few days in the year where there is an eventual risk of glint from the PV modules to landing airplanes. These particular days are 72 to 75 (2nd week of March - morning time) and 80 to 83 (3rd week of March - evening time). Because of yearly simmetry, the same occurs in mid-October.

Fig. 16 shows sun coordinates for a typical day in these periods (day 73). Interference with landing path occurs at around 07:37 hours, sun azimuth is -84° and elevation only 3°. Therefore airplanes reaching Calexico airport runway from the West end will have the sun disc just in front of them. It is considered that glint effect is neglegible when compared to direct sun light exposure, as in this case.

Similarly, planes landing or launching from the East at day (say) 82, will be facing the sun disc at sunset, and again the risk of glint is negligible when compared to the light intensity of direct sun.

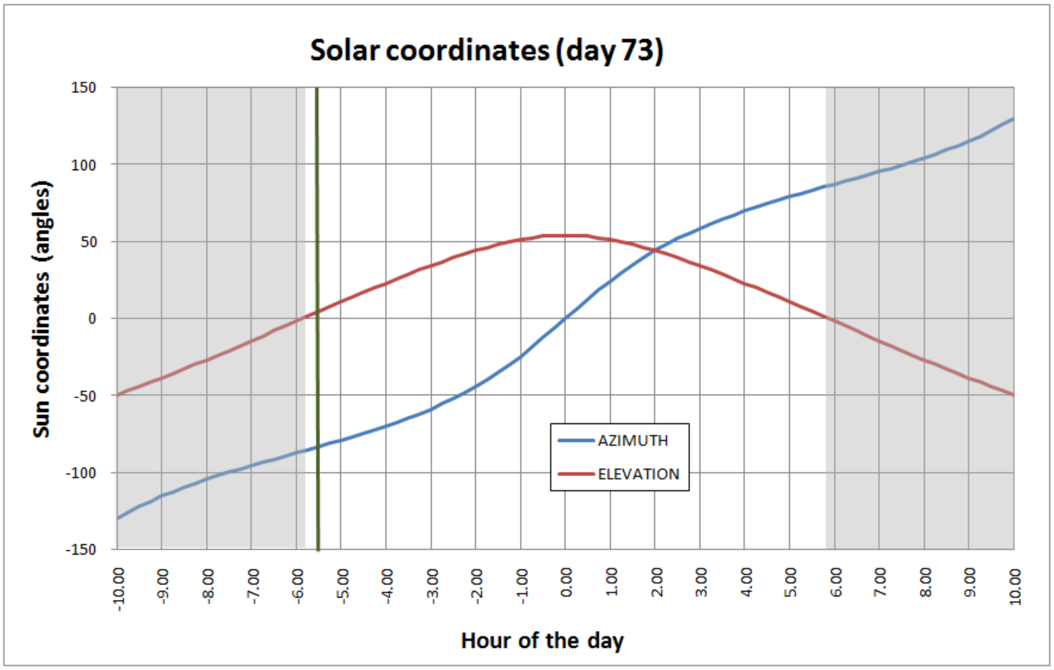
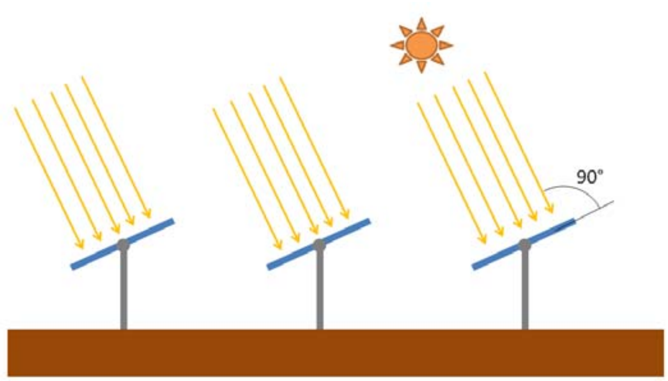



*Fig 16.- Sun postion for selected typical interference day – Green vertical line shows time of interference with airplane landing path.*

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.



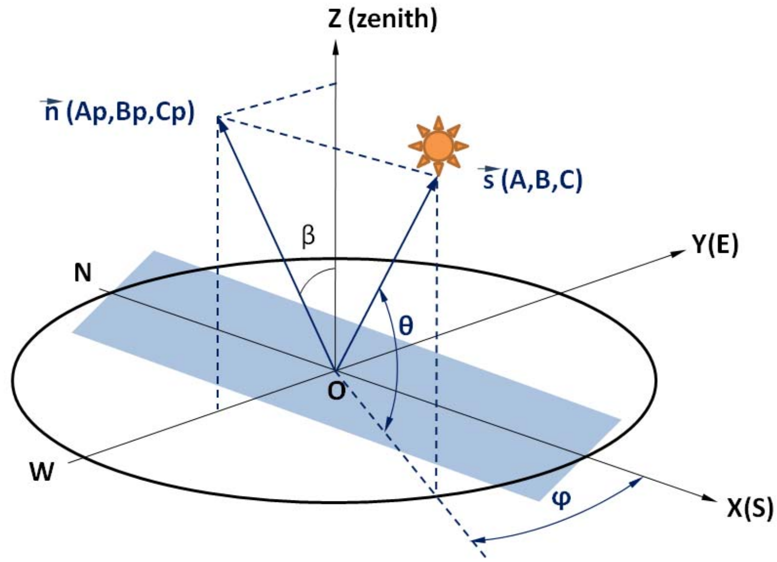



*Fig 17.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\ A_p + B\ B_p + C\ C_p$$

this can be written as

$$\cos\gamma = -B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\ (\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad\qquad \tan\beta = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

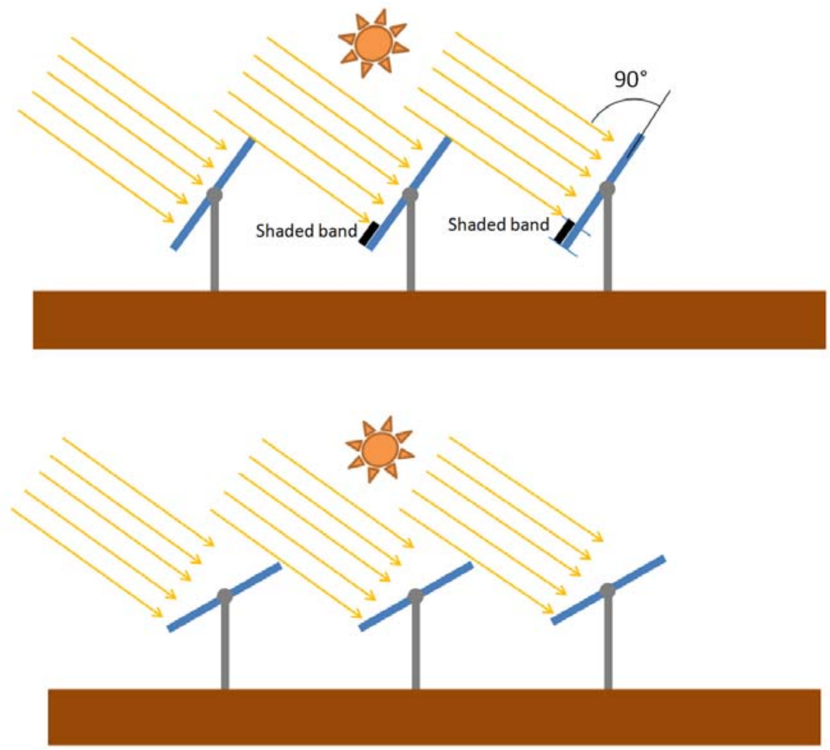



*Fig 18.- Above: Mutual shading without backtracking.*
*Below: Backtracking corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons.

Fig. 19 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

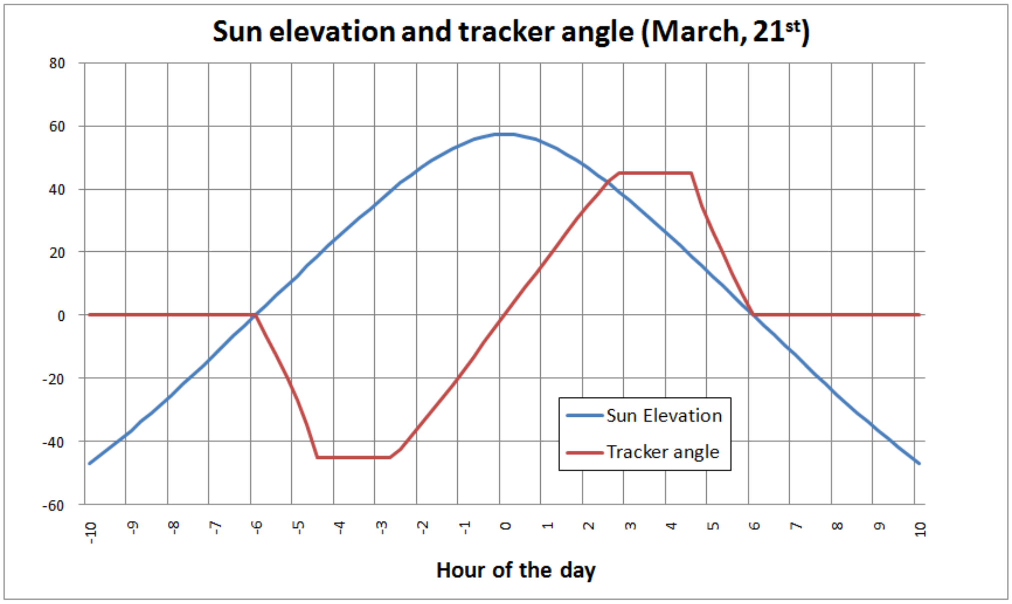



*Fig 19.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 20,

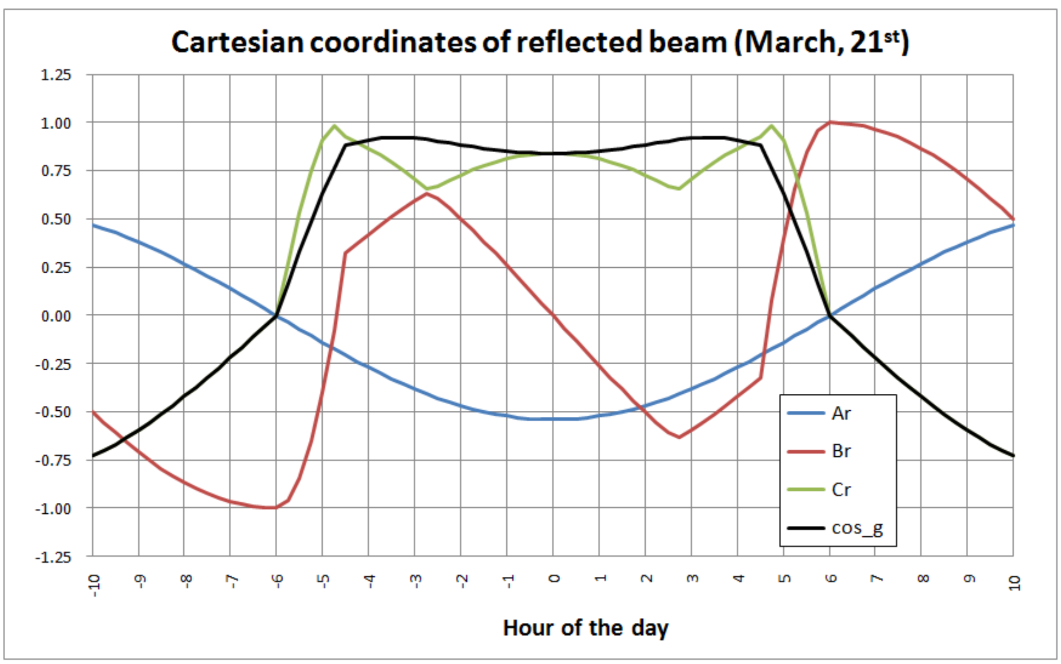



*Fig 20.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at Calexico

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

As an example, Fig. 21 shows the azimuth and elevation angle of the reflected beam. The green line defines the flight-plane azimuth condition for Calexico, thus the reflected beam will be contained in this particular plane at 8:45am and 3:00pm, but in both cases the beam elevation angle is well over 40°, so there is no risk for glint.

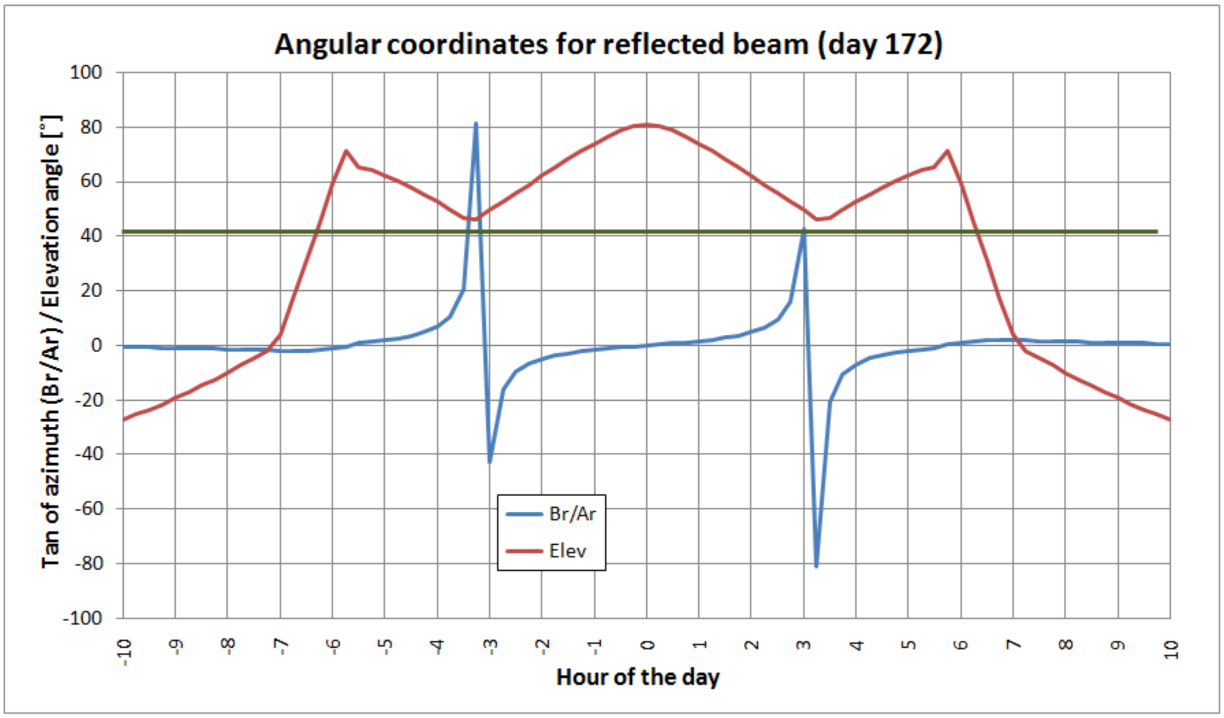



*Fig 21.- Angular coordinates for reflected beam (day 172)*

The same calculation is repeated for a complete year and results shown in Fig. 22.

It can be seen that whenever the reflected beam is contained in the flight-plane, its elevation angle is very far from the usual approaching or launching angles to the airport, so there is no risk of glint with trackers.

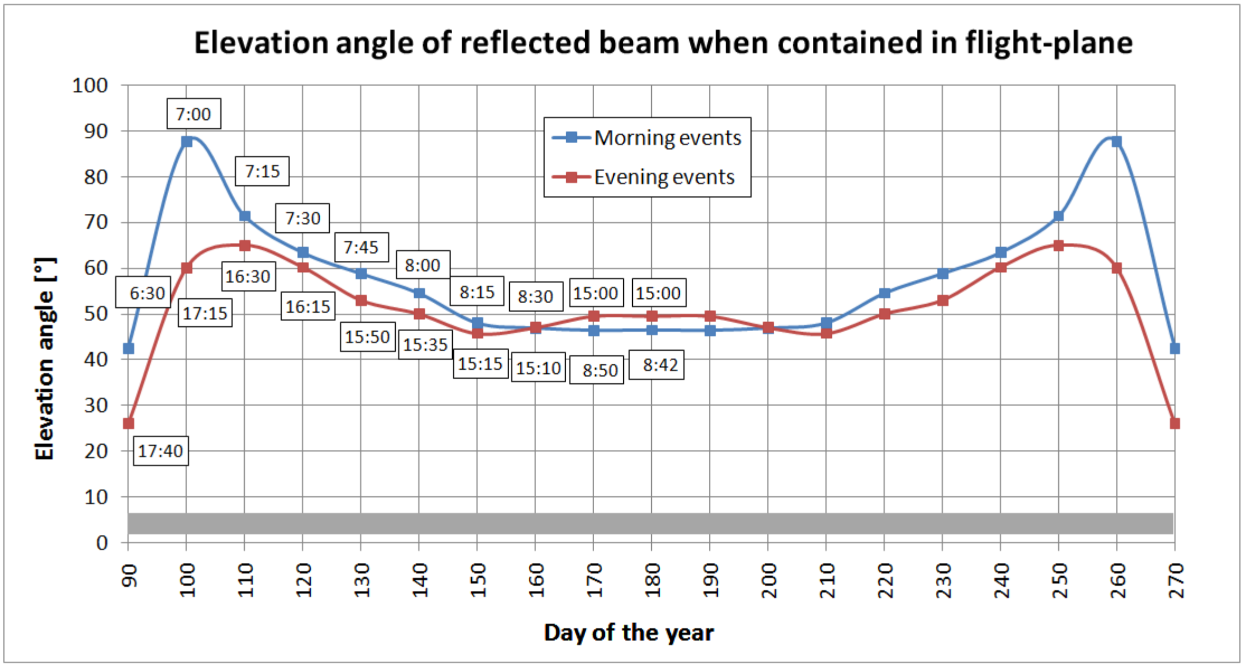



*Fig 21.- One year results for elevation angles of reflected beam when contained in the flight plane. For the six month period from October to March the reflected beam is never contained in the flight-plane.*

# 4 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected, but this might produce some glint to KVPs. For this Project, it is considered that airplanes landing at or taking-off from Calexico airport might be exposed to glint.

To determine the glint risk, a geometric analysis is done for both scenarios: Fixed tilt PV modules and Horizontal Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes (that is 35040 points). All mathematical expressions hereby described are implemented in a computer routine.

In the case of fixed tilt PV fields it has been demonstrated that, in the few cases when there is some risk of glint by PV modules, the airplane will also be directly facing the sun disk, so it can be concluded that glint from PV modules will not have any relevant effect on airplanes' visibility, nor deteriorate the actual approaching or launching flight conditions.

If the PV plant is built with horizontal axis tracking technology, the eventual reflected beam would have a high elevation angle (that is, pointing upwards), so no interference with approaching or launching airplanes from Calexico airport will ever occur.

The same conclusions can be extended to other tracking technologies (single inclined axis or double axis trackers). With these devices, the tracking efficiency is higher than with horizontal axis trackers, therefore the incident angle is even lower, and the reflected beam will be pointing the sun disk more closely. Risk for glint when landing of launching might theoretically occur only at low sun elevation angles (i.e., sunrise or sunset); however, during these particular hours the backtracking technology modifies the tracking algorithm to avoid mutual shading thus re-orientating the reflected beams upwards, far from the flight path.

It is concluded that this Project will not have any relevant glint effect for airplanes landing at or taking-off from Calexico airport. This is also applicable regardless of whether the Project is built in one, two or more phases.

# APPENDIX H

## Visualization Study

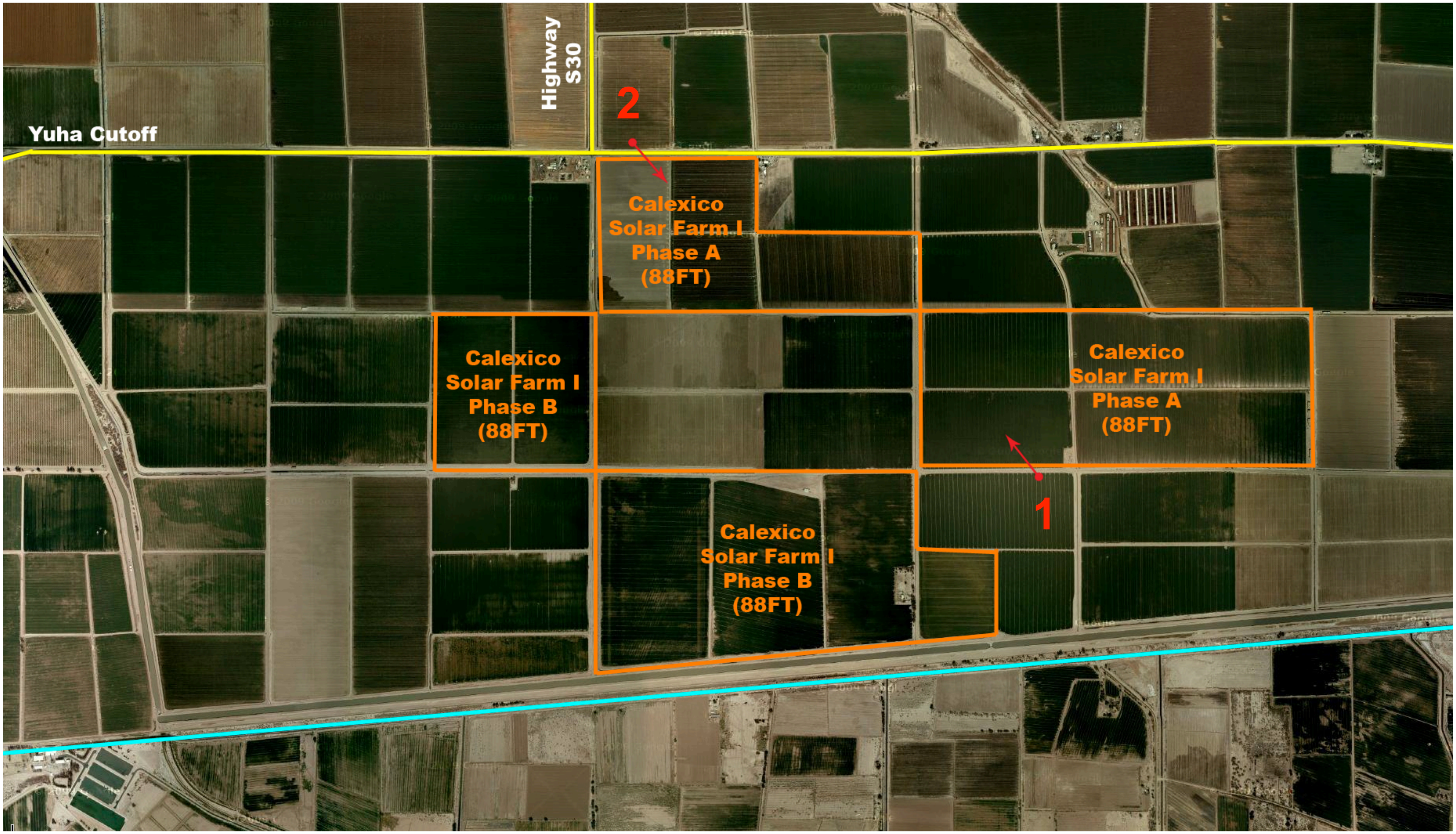
# Visualization Study

# Calexico Solar Farm I

Visualizations by

modative

Design
Develop
Build




Final design and location/route may be revised prior to issuance of permits

Viewshed Locations

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT

Key Plan

KEY

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Anza Road

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT

Existing

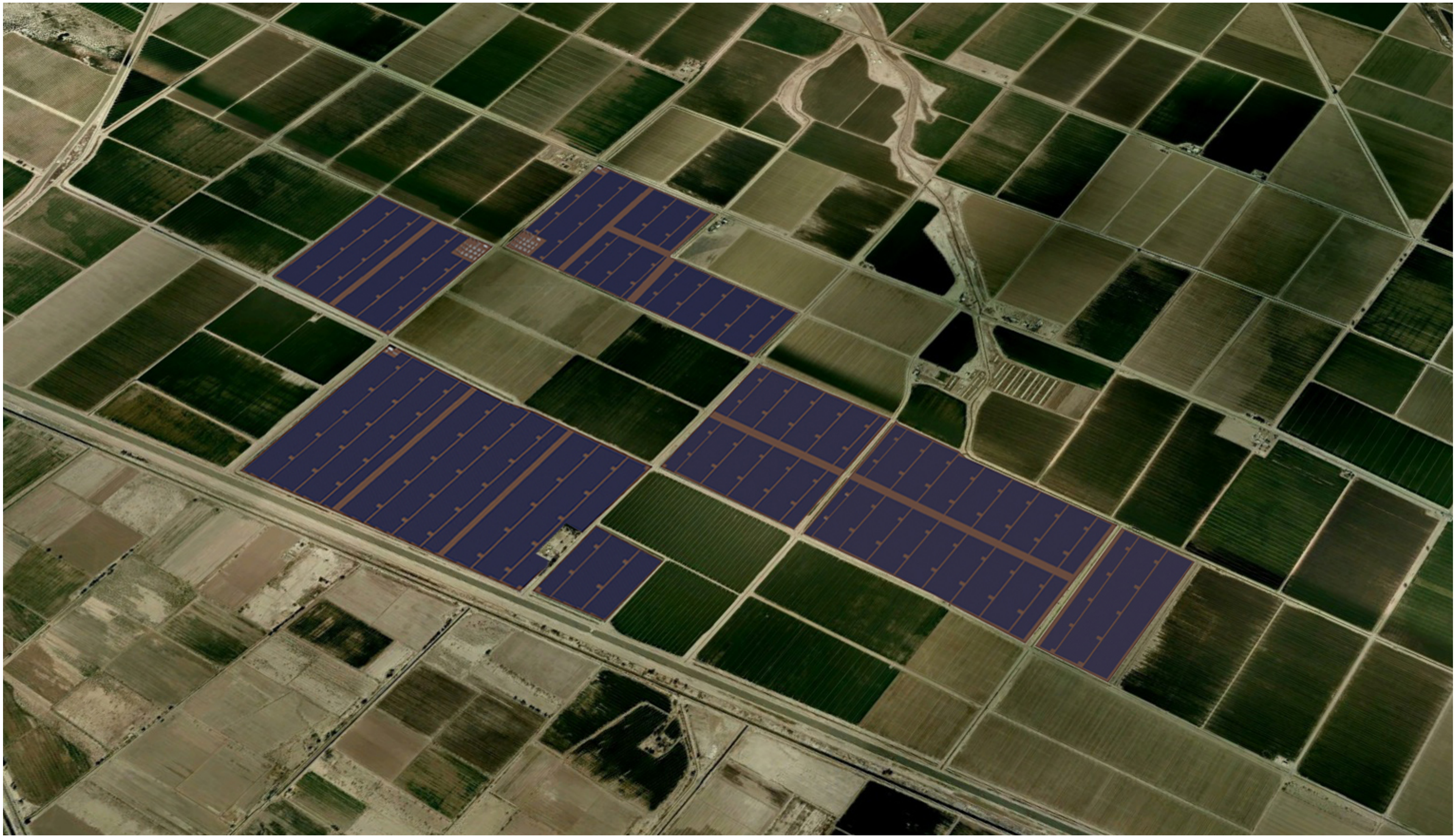
Proposed

Final design and location/route may be revised prior to issuance of permits

Looking South-East Along Highway 98

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT



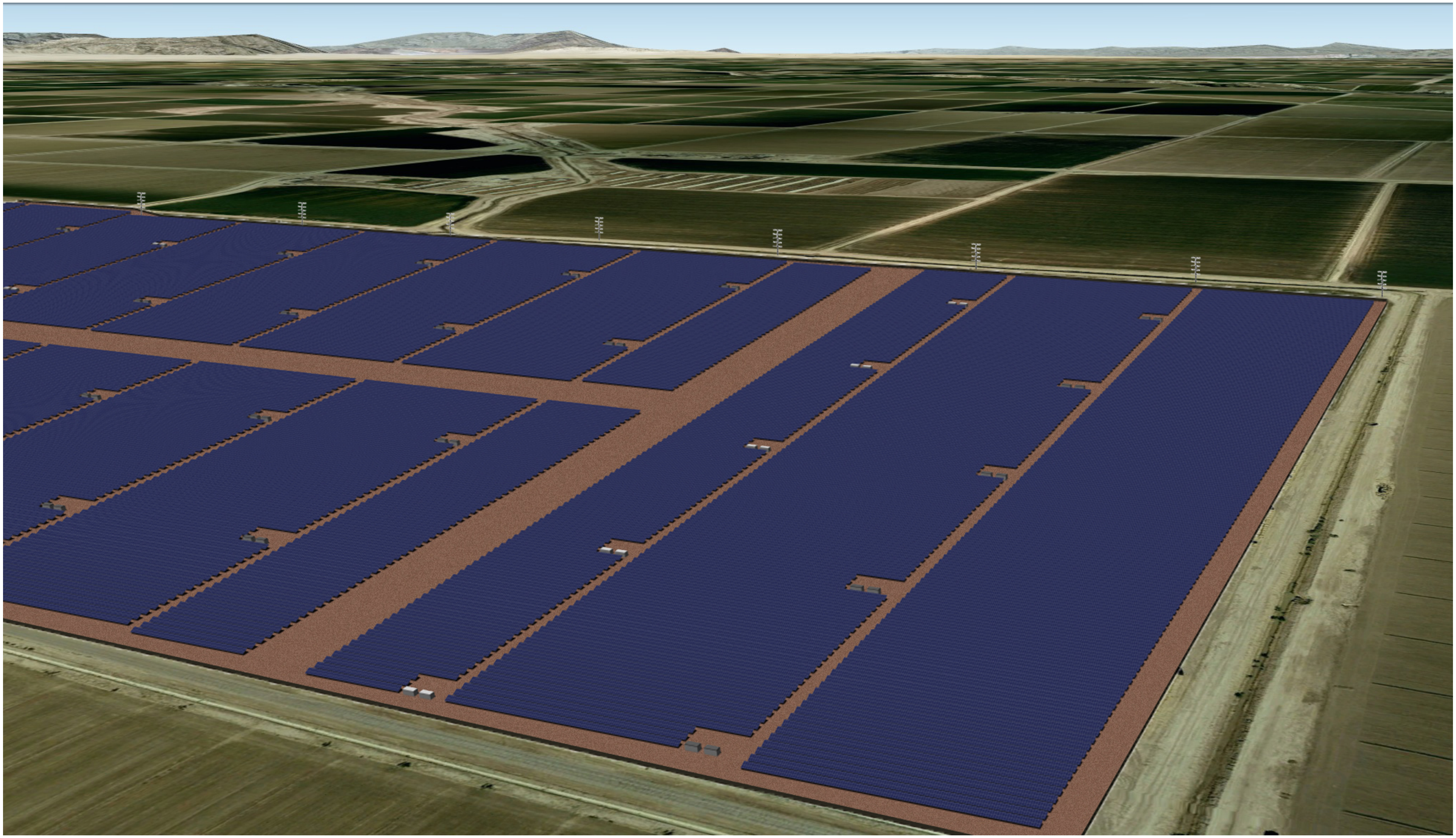
Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT



Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm I (88FT)**

**date:** 7/15/11
**project:** 88FT

# APPENDIX F

## Glare Analysis for Ground Traffic

April 11, 2011

Good Company
65 Centennial Loop, Suite B
Eugene, Oregon 97401

Mr. Thomas Buttgenbach
89MA 8ME LLC
10100 Santa Monica Blvd, Suite 300
Los Angeles, CA 90067

Dear Mr. Thomas Buttgenbach:

The purpose of this technical memo is to augment the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report. *The Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report analyzed the 89MA project as being constructed in one phase and under one conditional use permit. However after completing the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report, the project's construction plan was modified to reflect a second conditional use permit that would allow the project to be constructed in more than one phase. We have reviewed and analyzed this modification and have determined that the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report remain unchanged. In other words, the development of the project in more than one phase or CUP does not change the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report. Please call me if you have any questions.

Joshua Skov

Principal, Good Company

## Potential Impacts from Reflection of Proposed Calexico Solar Farm II

Draft Date: April 14, 2011

### KEY FINDINGS

- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection above the nearby buildings and ground-traffic corridors.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Calexico Solar Farm II, which is located 1.5 miles west of Calexico in Imperial County, California. The project site is comprised of four parcels of land with a total area of 1,477 acres. See Appendix A for aerial photographs of the site.

The proposed project is a ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the proposed Calexico Solar Farm II on nearby roads and buildings. The reflection impacts on aircraft using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

### Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules.

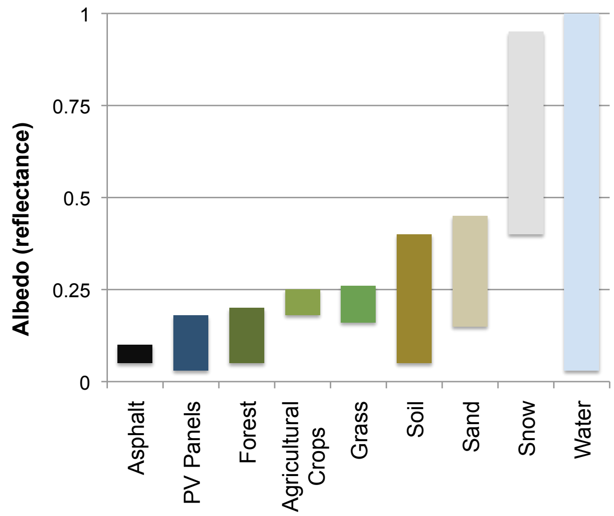
In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.
[2] Ibid.

### Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around 0.10.[3] By comparison, sand has an albedo between 0.15 and 0.45 and agricultural vegetation has an albedo between 0.18 and 0.25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

**Figure 1:** Albedo comparison for various surfaces.




### Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs midday on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 2 below). The potential impact at that moment is the best proxy for maximum impact overall.

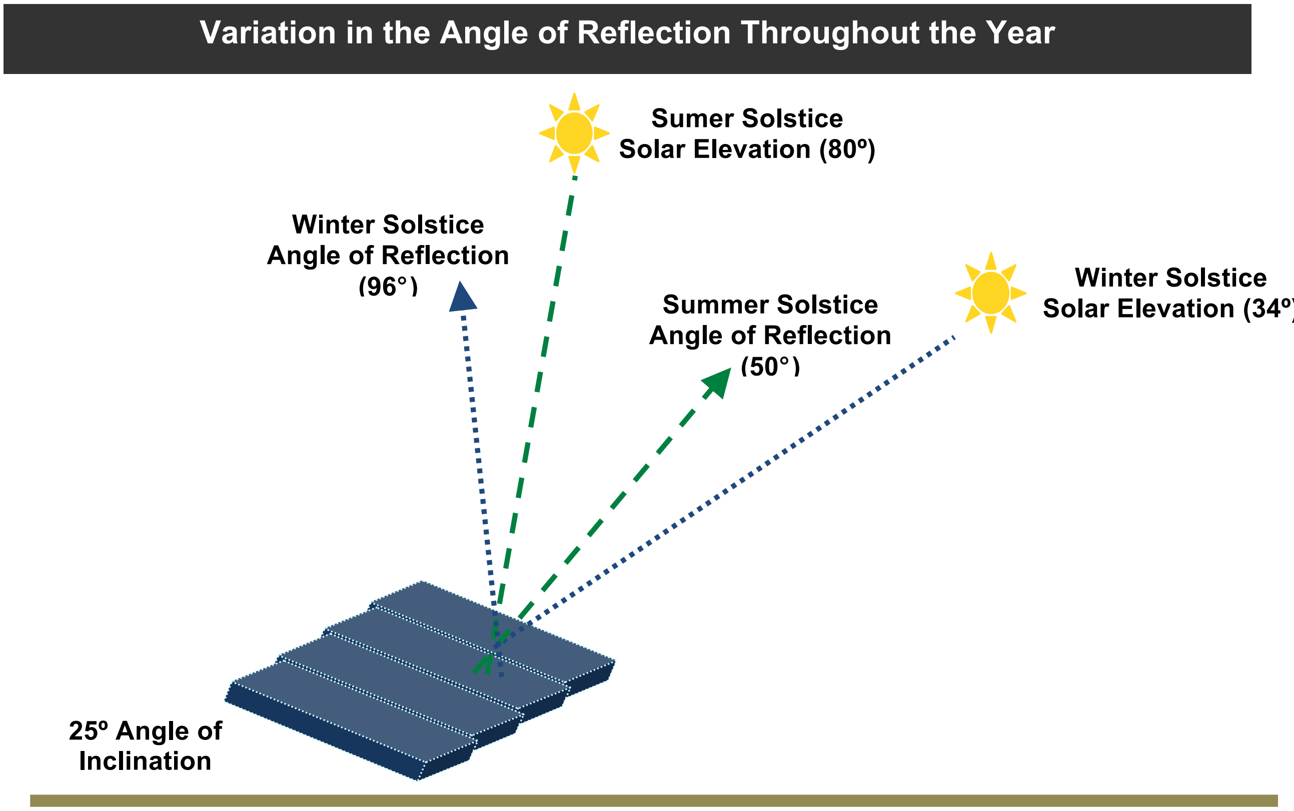
During summer solstice at the proposed project's latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is unlikely that vehicles traveling on nearby roads or buildings south of the project site would be adversely affected by a direct reflection of sunlight from this angle. Continue reading this section for more details.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed project's latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

---

[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.39 degrees north.

**Figure 2:** The range of the sun's angle-of-reflection depending on the time of year.




The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 20 feet (the approximate distance from the southern edge of the Calexico Solar Farm II project, Parcel II, to the edge of Highway 98), the height of the reflected sunlight from the array would be nearly 24 feet in elevation, well above the California truck height limit of 14 feet. It is important to note that the other roads in the immediate vicinity of the proposed arrays are not major transportation corridors and as such are not expected to support significant passenger or commercial traffic. Highway 98 also travels east west and thus, vehicles on the road would not be directly facing the solar arrays that are north of the highway. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (and any indirect reflection).

The built structures closest to the Calexico Solar Farm II project site are a cluster of buildings (appearing to be barns and storage buildings), 30 feet south from the nearest edge of the Parcel III array. At this distance, the height of direct reflection is 36 feet. There is a residential neighborhood on the western edge of Mexicali, Mexico. These homes are 0.45 miles due south from the southern edge of Parcel III. At this distance, the elevation of direct glare would be over 0.5 miles high, the height of a 188-story building[6].

[6] This number of floors assumes a height of 15 feet per floor.

**Figure 3:** Map of the points listed in Figure 4 and the "on the ground" distance from each point to the array.

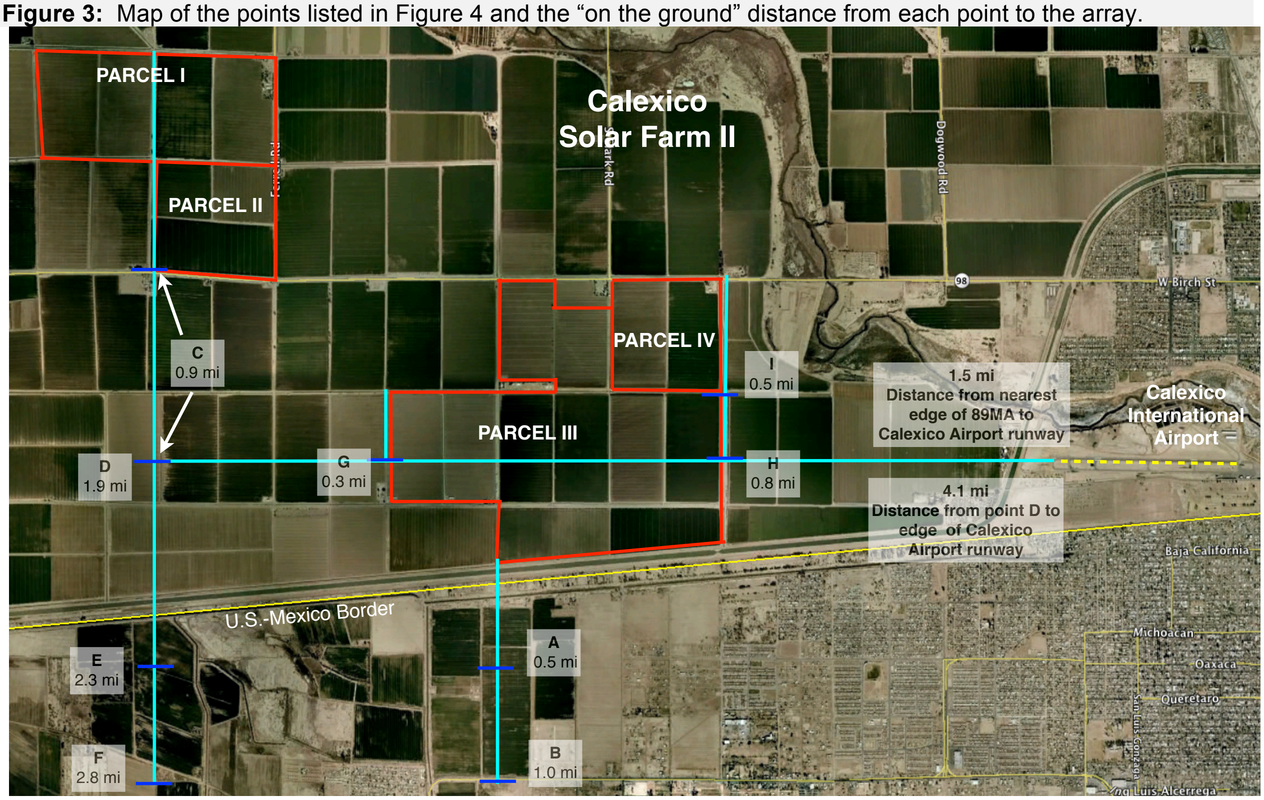



**Figure 4:** Elevation of direct reflection for the points shown on Figure 3.

| Point on Figure 3 | Elevation of Direct Reflection miles | feet |
|---|---|---|
| A | 0.60 | 3,147 |
| B | 1.19 | 6,294 |
| C | 1.07 | 5,665 |
| D | 2.26 | 11,954 |
| E | 2.74 | 14,472 |
| F | 3.34 | 17,619 |
| G | 0.36 | 1,890 |
| H | 0.60 | 3,147 |
| I | 0.95 | 5,032 |

## Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[7]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[8]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (and any indirect reflection).

## Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array the greatest potential for a low angle of reflection, that might impact the built environment, occurs midday on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At midday on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

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[7] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see "Panache Valley Solar Farm Project Glint and Glare Study" (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and "Topaz Solar Farm Reflection Study" (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).

[8] TrinaSolar. "Reflection Coefficient of Trina Solar Modules." Personal communication with Thomas Houghton, June 30, 2010.

## Appendix A: Glare Analysis Explanation

### Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[9] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

**Figure 8:** Angle of direct reflection on summer solstice (June 21).

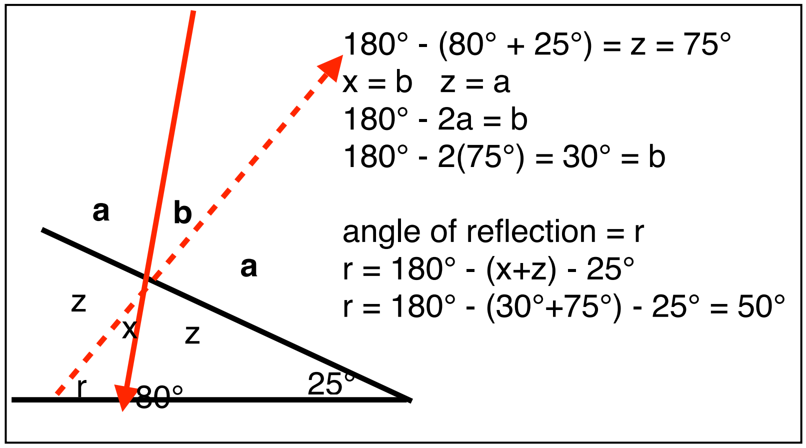
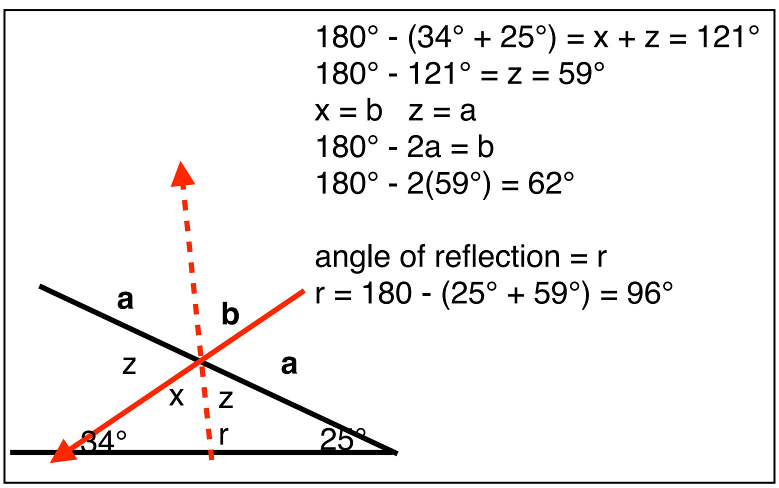



Figure 8 to the right depicts this reflection. All angles within a triangle summed equal 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

**Figure 9:** Angle of direct reflection on winter solstice (Dec. 21).



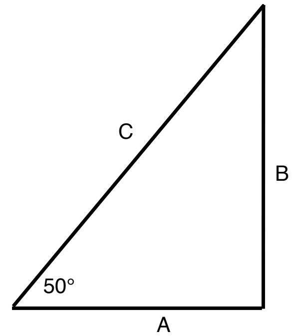

Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point during winter solstice on December 21st (see Figure 9, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[9] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

## Determining the Height of Reflection

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Calexico Solar Farm II. Figure 10 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

**Figure 10:** Calculation to determine direct reflection.

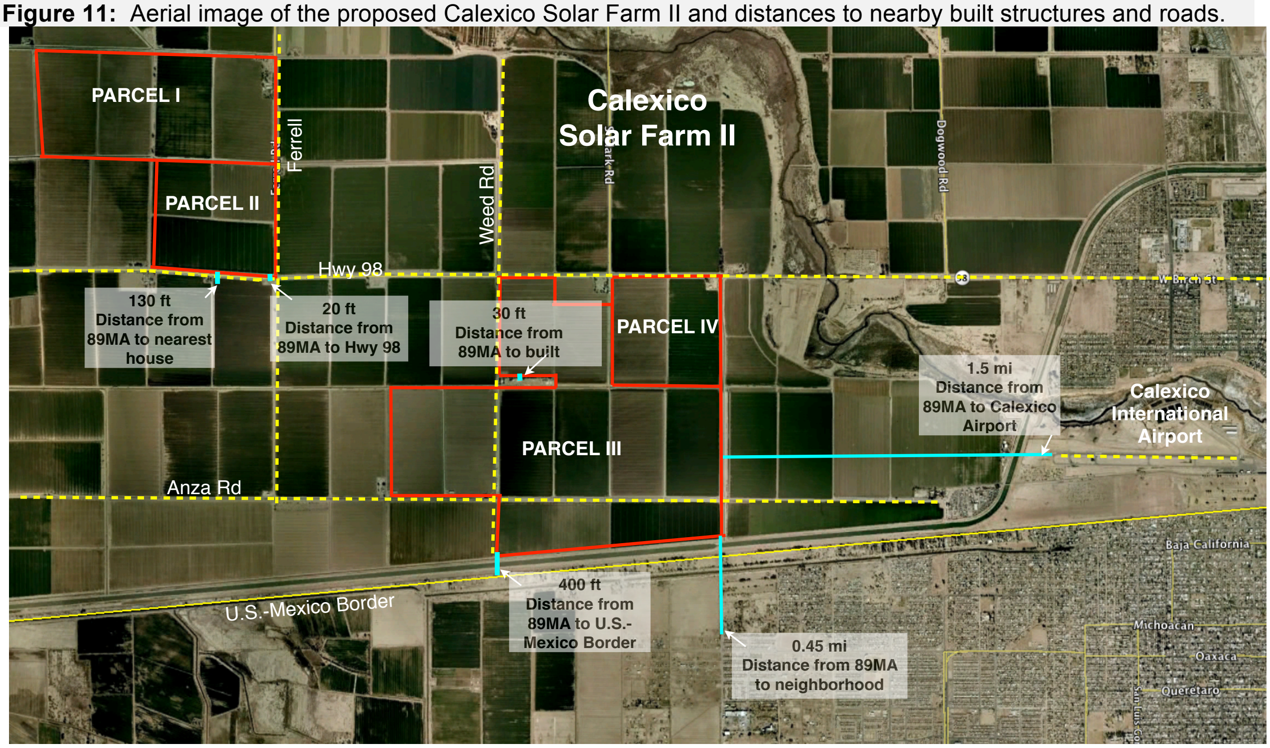



$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 11 is an aerial picture of the sited Calexico Solar Farm II from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico border (yellow line) as well as the four portions of the project which serve as the boundaries for the panel arrays in this project. Figure 11 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 11 describe the height of the direct reflection at the various distances shown by the blue lines.

**Figure 11:** Aerial image of the proposed Calexico Solar Farm II and distances to nearby built structures and roads.



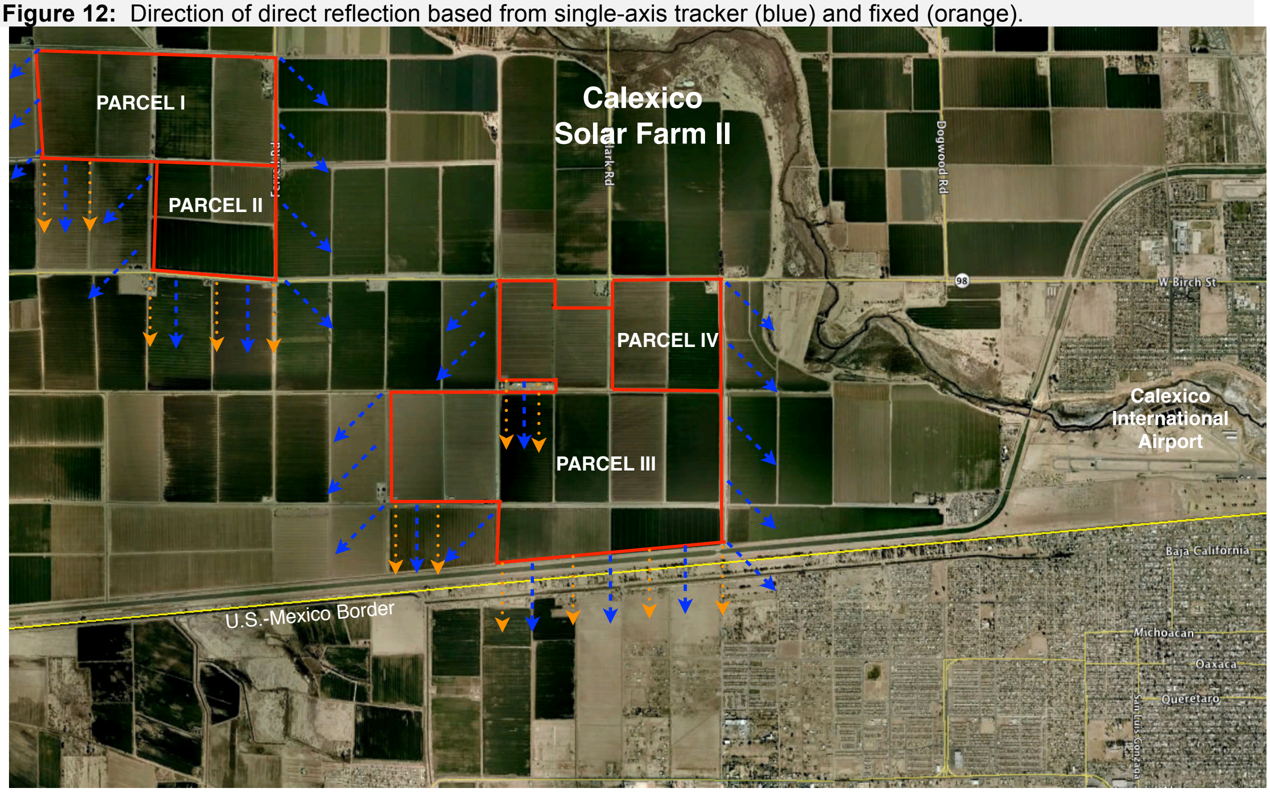

- At 20 feet from the solar panels the height of the reflection is already at 24 feet.
- At 30 feet from the solar panels the height of the reflection is at 35.8 feet or higher (depending on the time of year).
- At 130 feet from the solar panels the height of the reflection is 155 feet or higher.
- At 400 feet from the solar panels the height of the reflection is 477 feet or higher.

- At 0.45 miles from the solar panels the height of the reflection is 0.54 miles (2,832 feet) or higher.
- See the Reflectivity Analysis conducted by Aztec Engineering for details on potential impacts to aircraft utilizing Calexico International Airport.

## Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

**Figure 12:** Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).



# APPENDIX G

## Glare Analysis for Air Traffic

# CALEXICO Solar Farm II (89MA 8ME, LCC)

# REFLECTIVITY ANALYSIS

REVISION INDEX

| Page/Reason | REV | Date | PROD | CHECK | APRV |
|---|---|---|---|---|---|
| All | 0 | 04/13/2010 | JDL | JDL | JDL |
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# Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to a series of photovoltaic (PV) power plants being developed by 89MA 8ME, LLC. Project location is nearby the Calexico airport in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the corresponding airport runway if reflected sun light beam intersects the approaching flight path.

Fig. 1 shows the location of the future PV plant relative to Calexico airport.

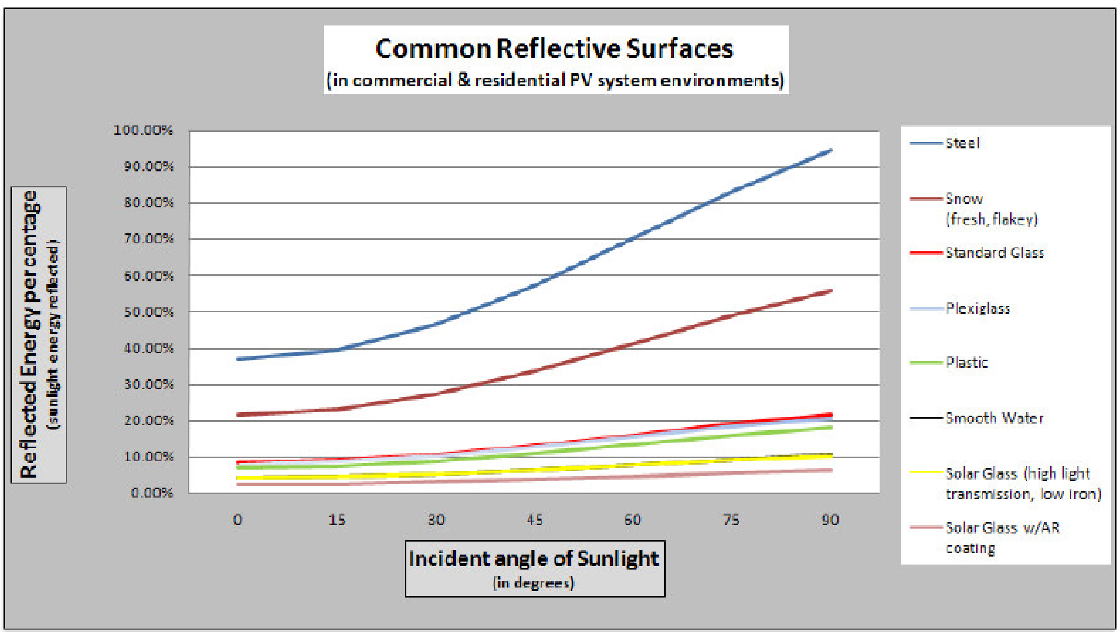

*Fig 1.- Location of PV Project and Calexico airport*

To evaluate the risk of direct sun light reflection events a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer direct reflection.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of the study:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the

reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and have negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules., for instance agricultural environment has higher Glare effect than PV modules.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to the airport runway.

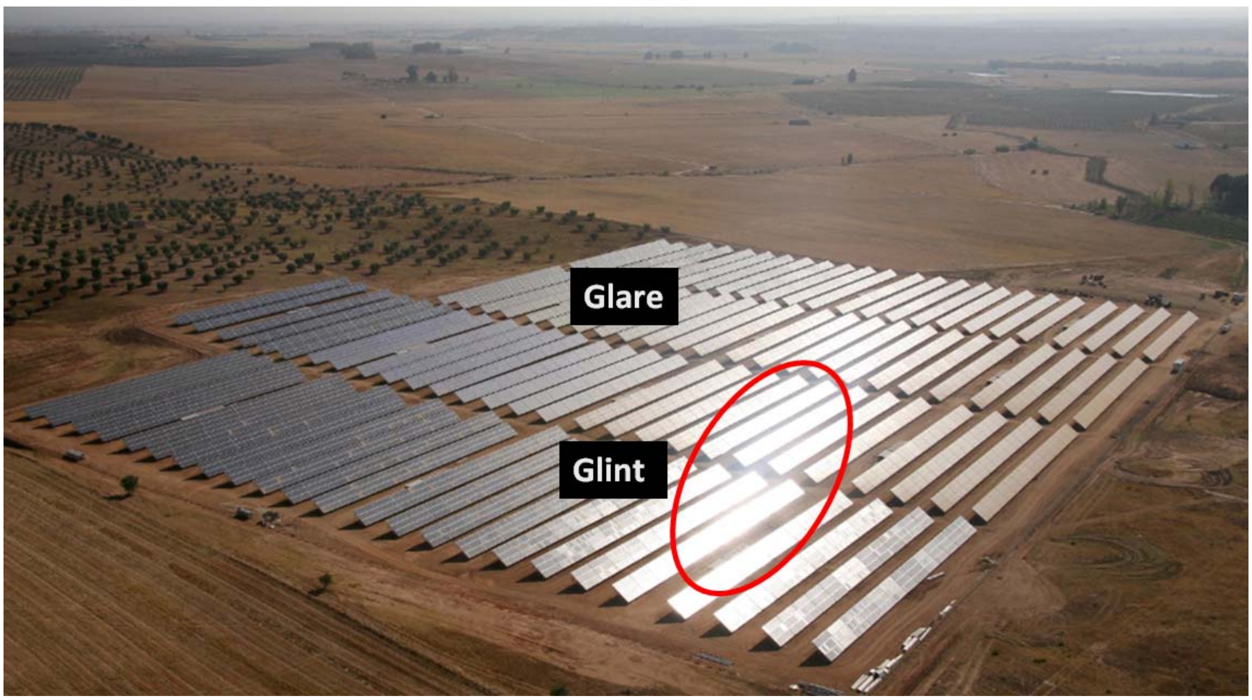



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Mathematical analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the future PV plant location, as shown in Fig. 3 below:


*Fig 3 .- Reference coordinate system*

Next image shows a 3D rendering of the future Project

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

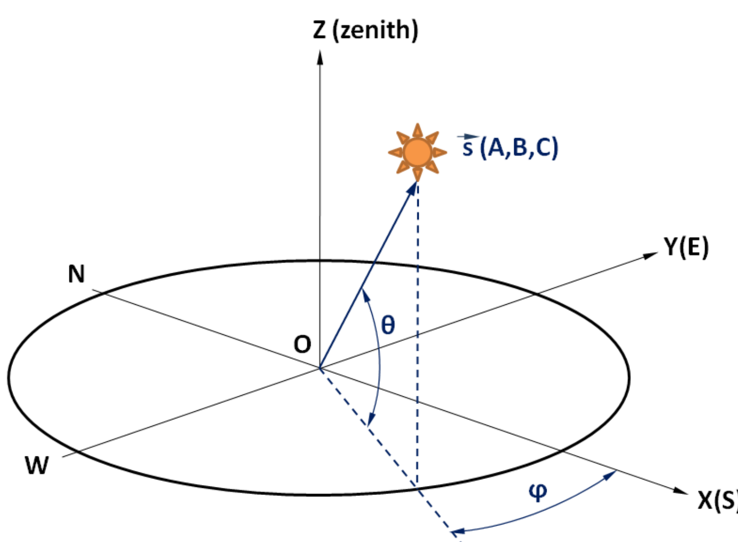



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta \ \cos\varphi$$
$$B = -\cos\theta \ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:
Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32,… until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc).
As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in the next graph:

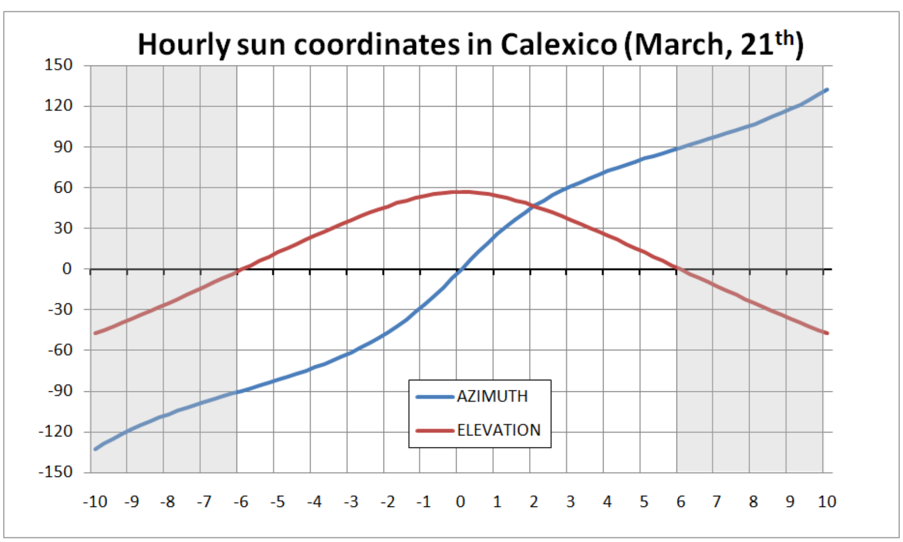



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

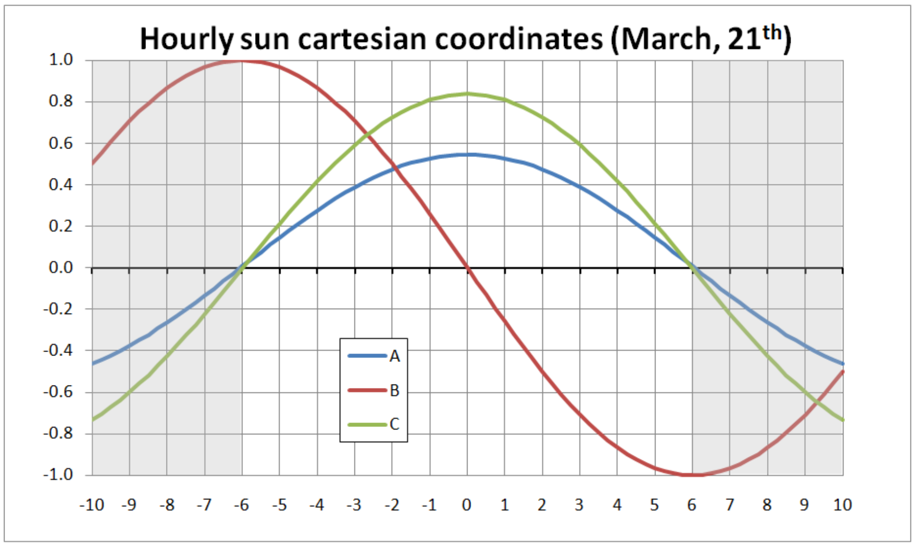



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located at the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

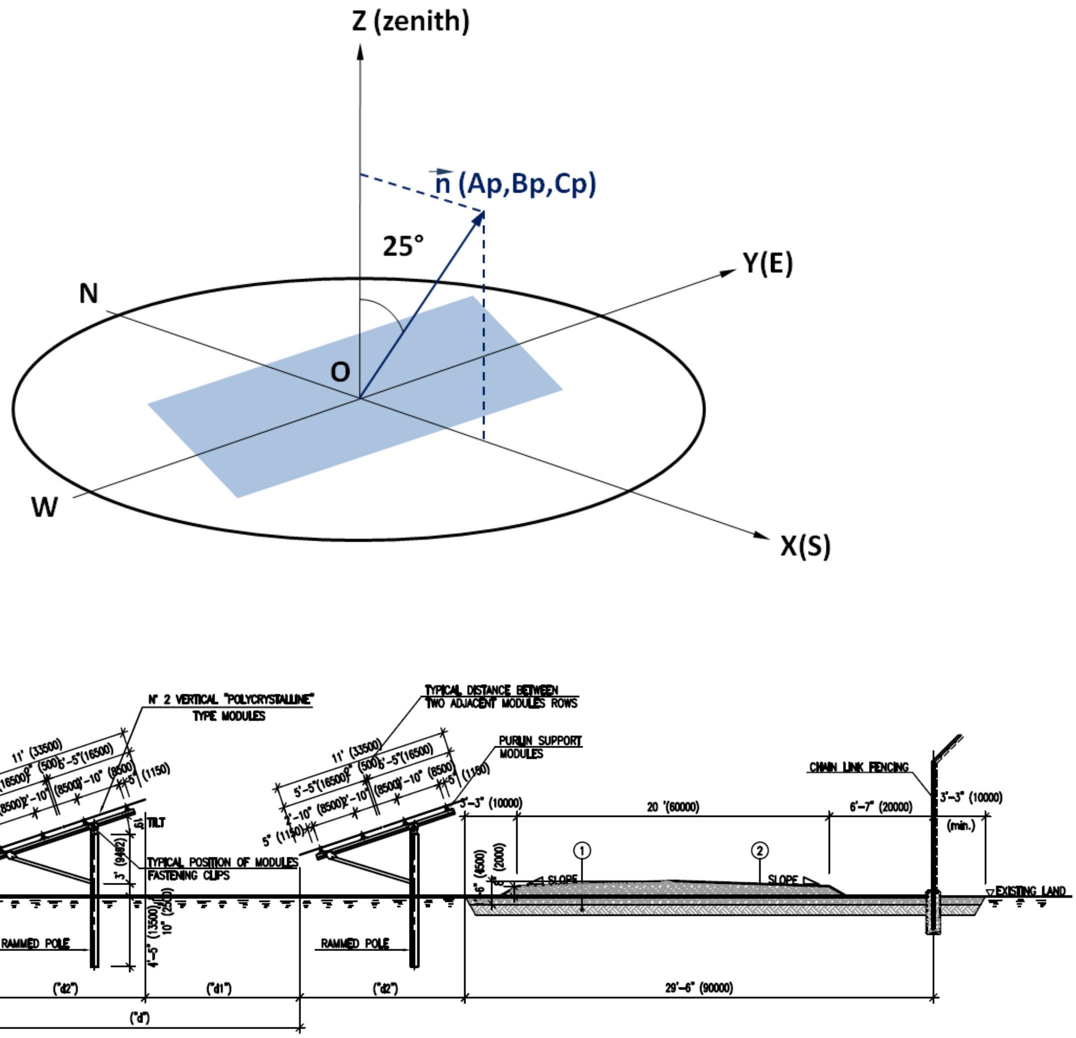



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:

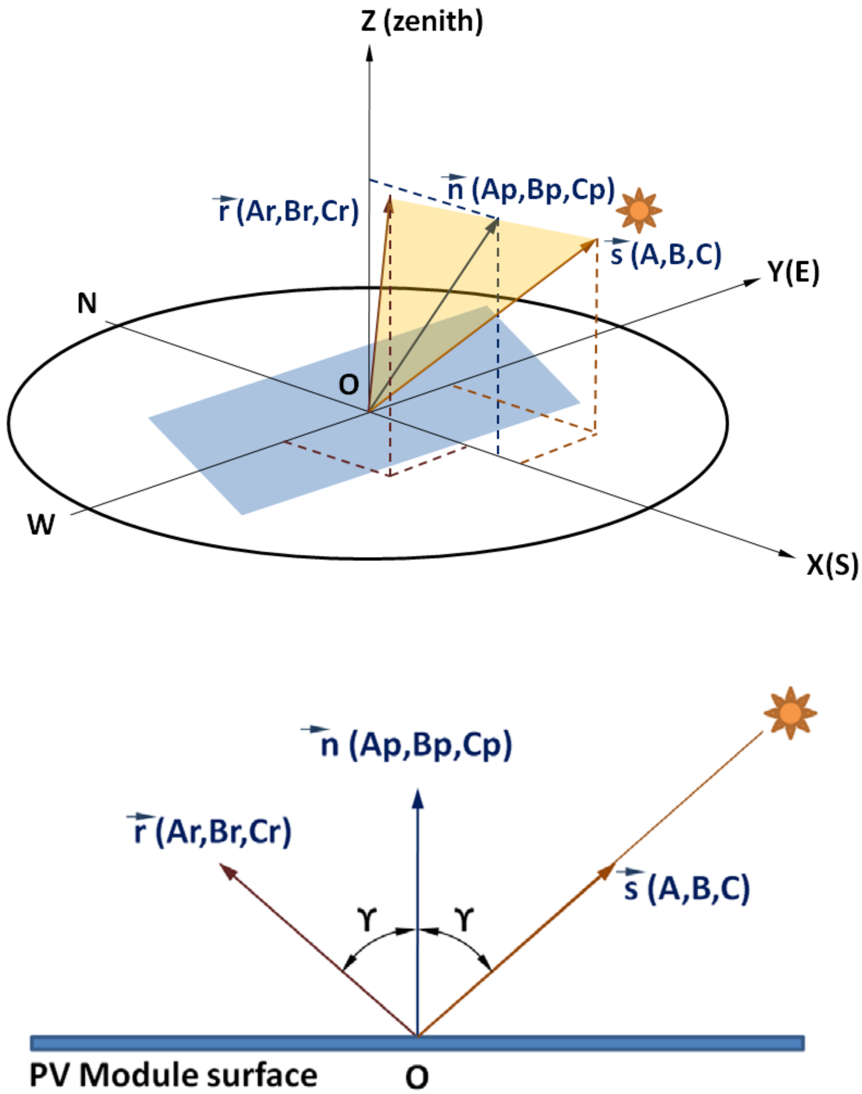



*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\, \vec{n} - \vec{s}$$

and its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\, A_p - A$$
$$B_r = 2\ \cos\gamma\, B_p - B$$
$$C_r = 2\ \cos\gamma\, C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

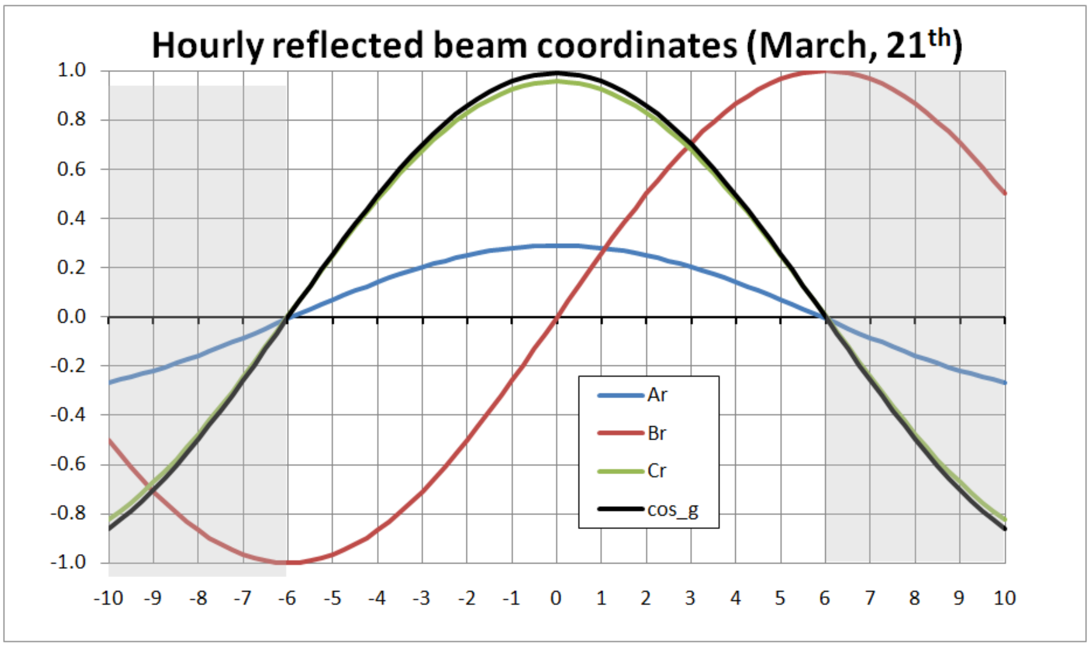



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity at Calexico runway (fixed systems)

To define the location of relevant KVP it is hereby assumed that the approaching airplane follows a straight line contained in a vertical plane (the "flight plane") that also contains the runway axis (Fig. 10).

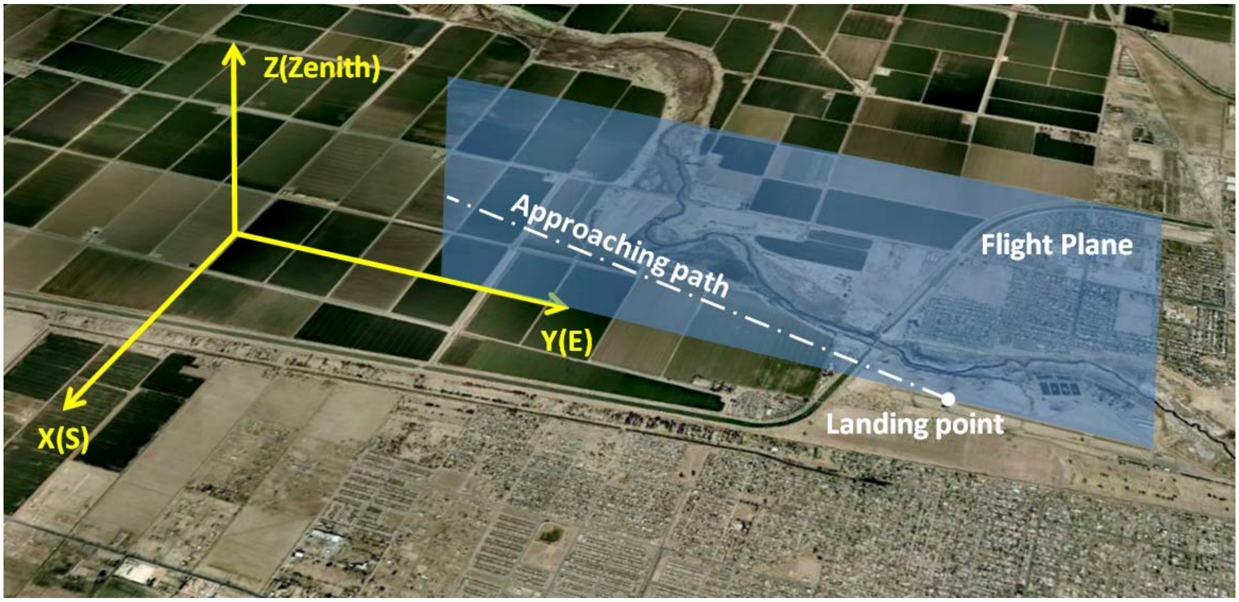



*Fig 10.- Geometry of approaching path*

The vertical flight plane, containing the approaching path, is defined by the following equation in the reference Cartesian axis system:

$$\Pi \equiv 0.9997\ x - 0.0239\ y = 0$$

The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

Runway azimut is 88.63°. Cartesian coordinates for any reflected beam r = (Ar, Br, Cr), if contained in the flight plane, shall satisfy the following condition (beam azimuth):

$$\frac{B_r}{A_r} = \tan\ 88.63° = 41.814$$

The angle between the horizontal plane and the reflected vector (reflection elevation angle) is given by

$$\tan \theta_r = \frac{C_r}{\sqrt{A_r^2 + B_r^2}}$$

Fig. 14 shows the hourly evolution of the above functions for a sample day (March, 2nd)

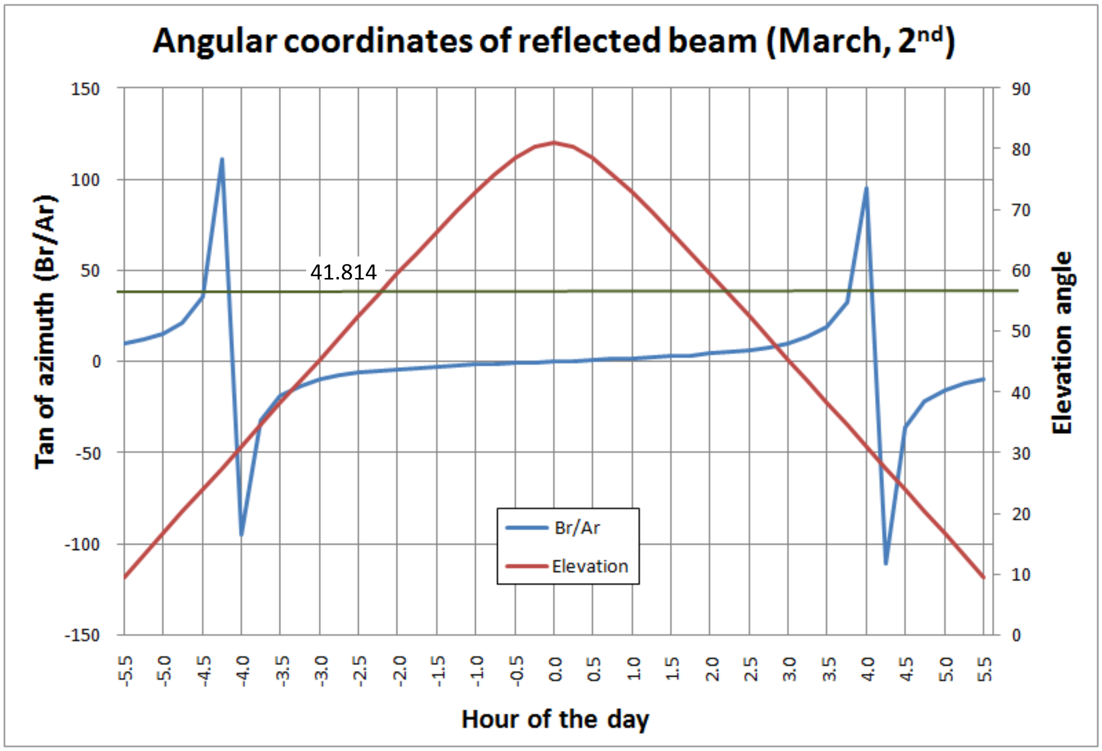
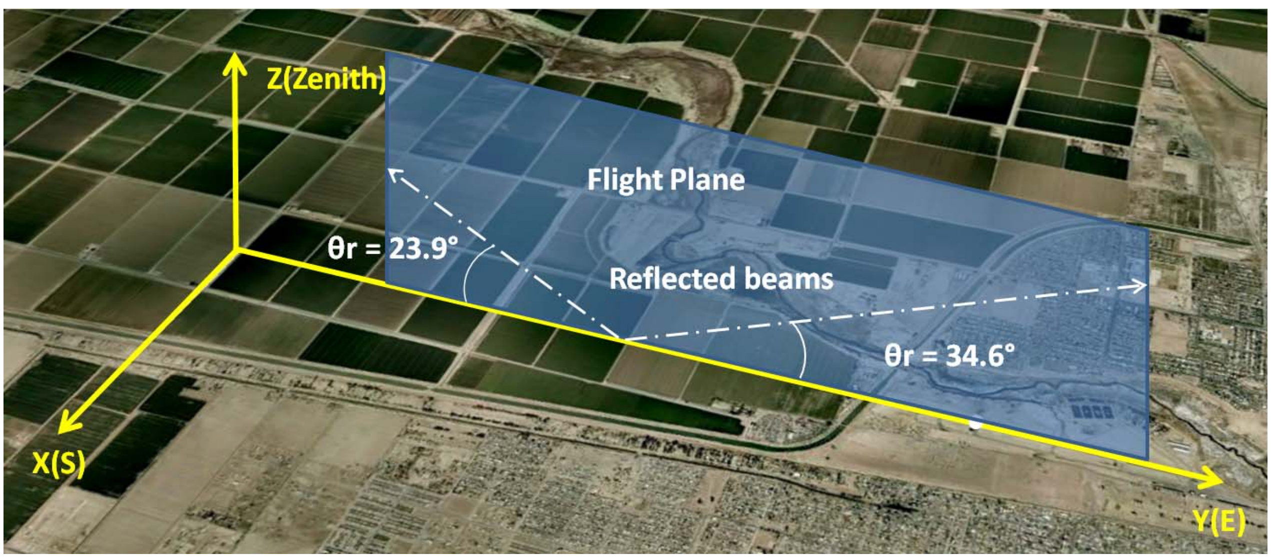



*Fig 14.- Angular coordinates of reflected beam (March, 2nd)*

It can be seen that the reflected beam will be contained in the flight plane at 07:30h (after sunrise) and at 15:45h (before sunset). The reflected beam will be pointing upwards with an angle of 23.9° and 34.6° respectively.




Obviously, the reflection held at 07:30 would affect airplanes landing Calexico from West, while the reflection held at 15:45h would afect airplanes landing or launching from East. In both cases, a long-term glint exposure would only occur if the airplanes were landing at the same particular angles (i.e., 23.9° and 34.6° respectively). It should be noted that normal landing angles are within the range of 3° and 6°, so in this particular day no risk of prolonged glint is possible.

The same procedure is repeated for all days in a year. Results in Fig.15 shows the elevation angle of the reflected beam in function of the day, whenever the in-plane condition occurs. Bandwith between estimated minimum and maximum airplane landing angles (3° and 6°) is superimposed :

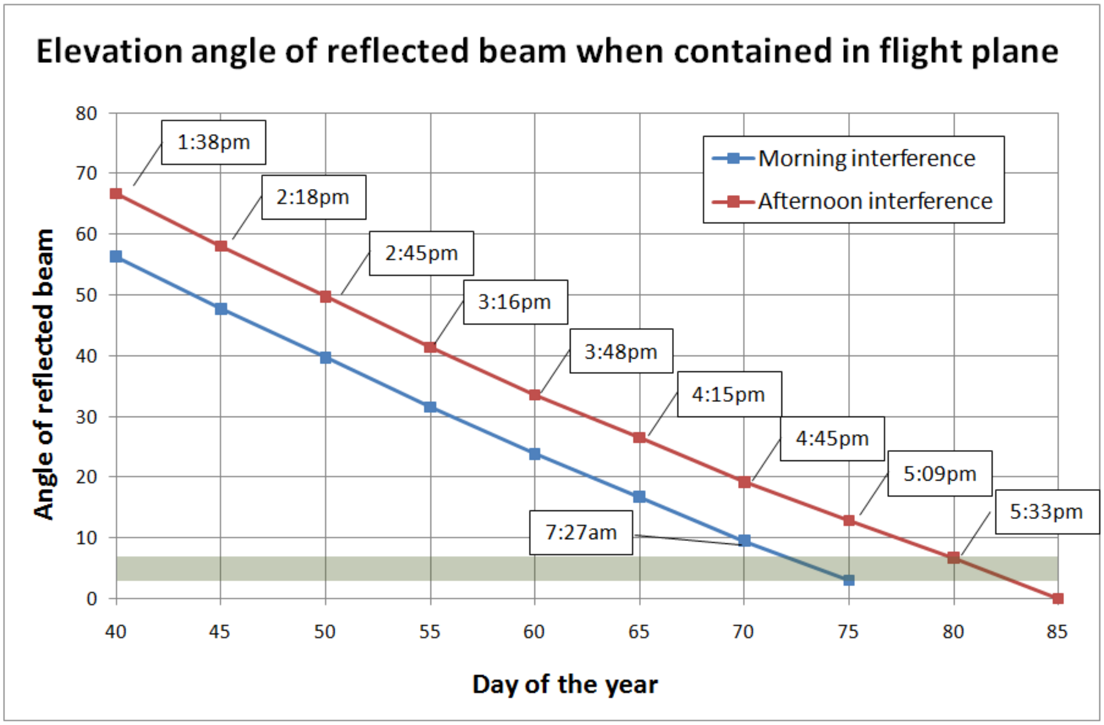



*Fig 15.- Reflected beam elevation angle and landing angles – Runway 29*

There are a few days in the year where there is an eventual risk of glint from the PV modules to landing airplanes. These particular days are 72 to 75 (2nd week of March - morning time) and 80 to 83 (3rd week of March - evening time). Because of yearly simmetry, the same occurs in mid-October.

Fig. 16 shows sun coordinates for a typical day in these periods (day 73). Interference with landing path occurs at around 07:37 hours, sun azimuth is -84° and elevation only 3°. Therefore airplanes reaching Calexico airport runway from the West end will have the sun disc just in front of them. It is considered that glint effect is neglegible when compared to direct sun light exposure, as in this case.

Similarly, planes landing or launching from the East at day (say) 82, will be facing the sun disc at sunset, and again the risk of glint is negligible when compared to the light intensity of direct sun.

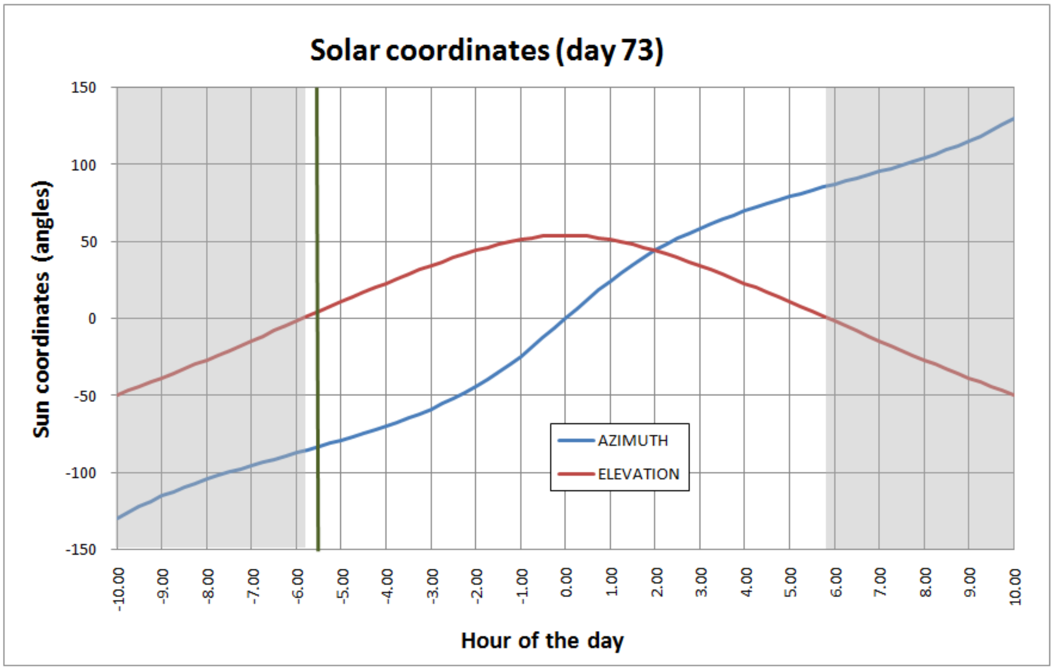
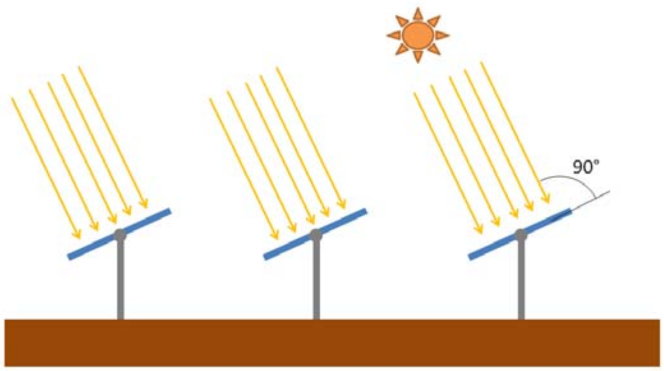



*Fig 16.- Sun postion for selected typical interference day – Green vertical line shows time of interference with airplane landing path.*

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.



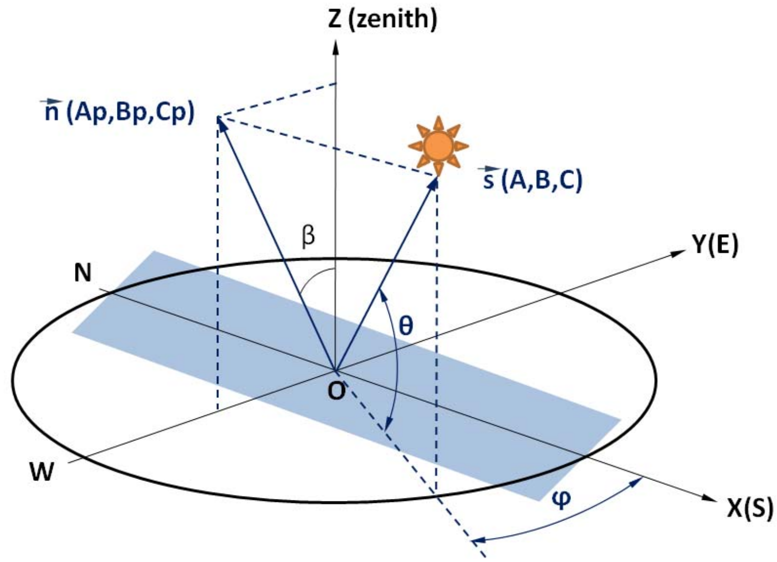



*Fig 17.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\ A_p + B\ B_p + \ C\ C_p$$

this can be written as

$$\cos\gamma = -\ B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\ (\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad \tan\beta\ = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

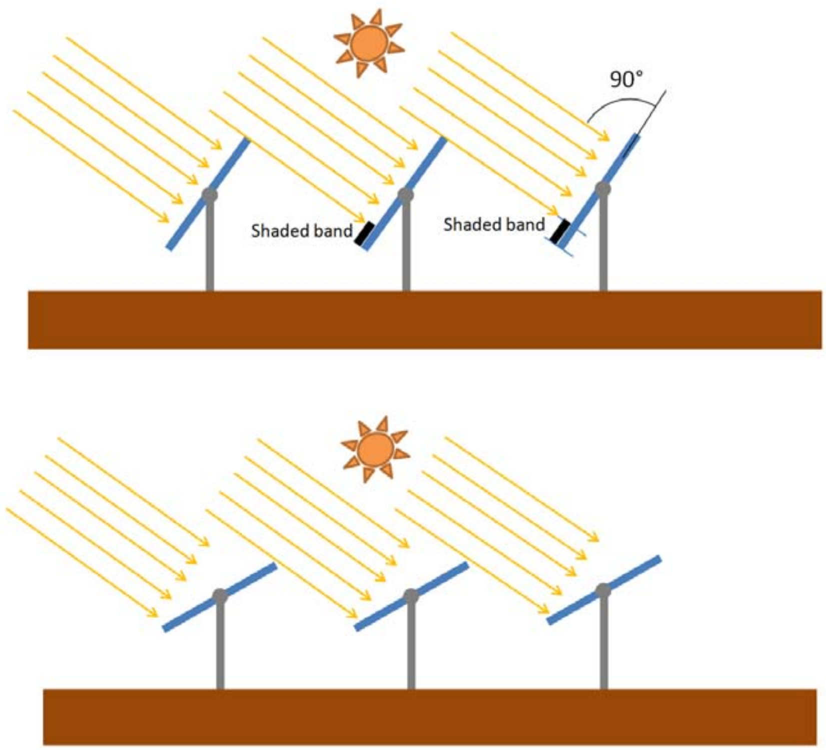



*Fig 18.- Above: Mutual shading without backtracking.*
*Below: Backtrackin corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons.

Fig. 19 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

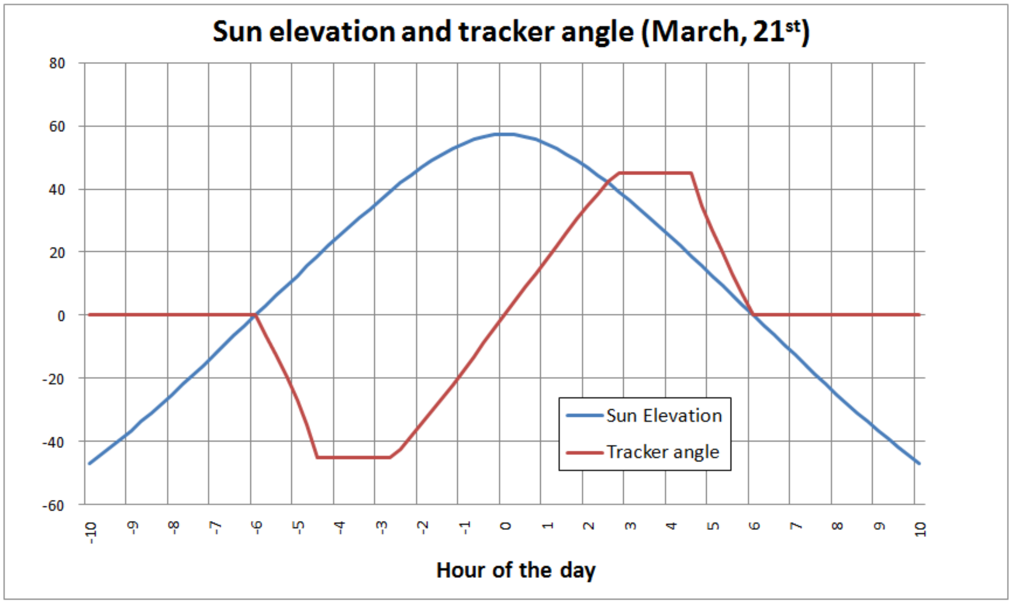



*Fig 19.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 20,

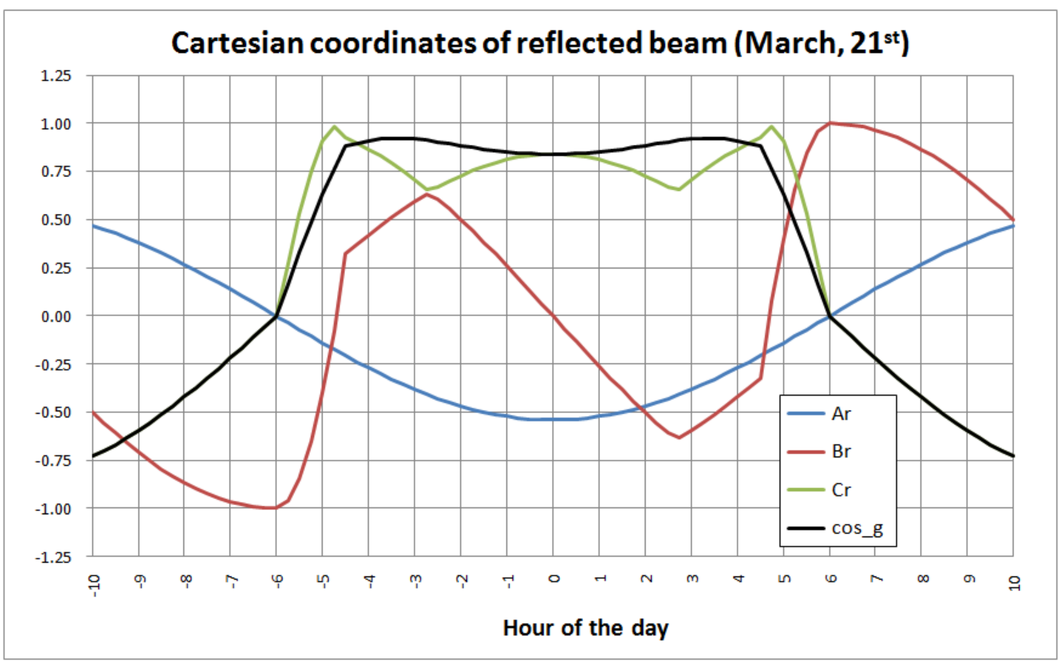



*Fig 20.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at Calexico

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

As an example, Fig. 21 shows the azimuth and elevation angle of the reflected beam. The green line defines the flight-plane azimuth condition for Calexico, thus the reflected beam will be contained in this particular plane at 8:45am and 3:00pm, but in both cases the beam elevation angle is well over 40°, so there is no risk for glint.

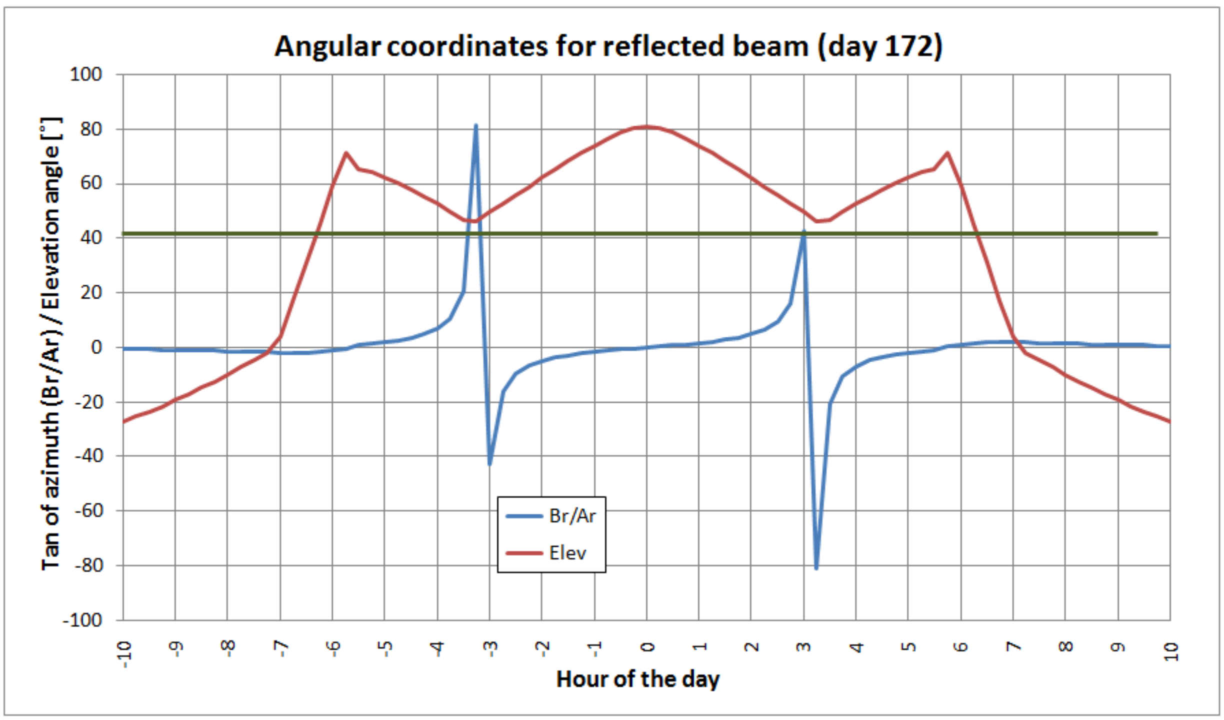



*Fig 21.- Angular coordinates for reflected beam (day 172)*

The same calculation is repeated for a complete year and results shown in Fig. 22.

It can be seen that whenever the reflected beam is contained in the flight-plane, its elevation angle is very far from the usual approaching or launching angles to the airport, so there is no risk of glint with trackers.

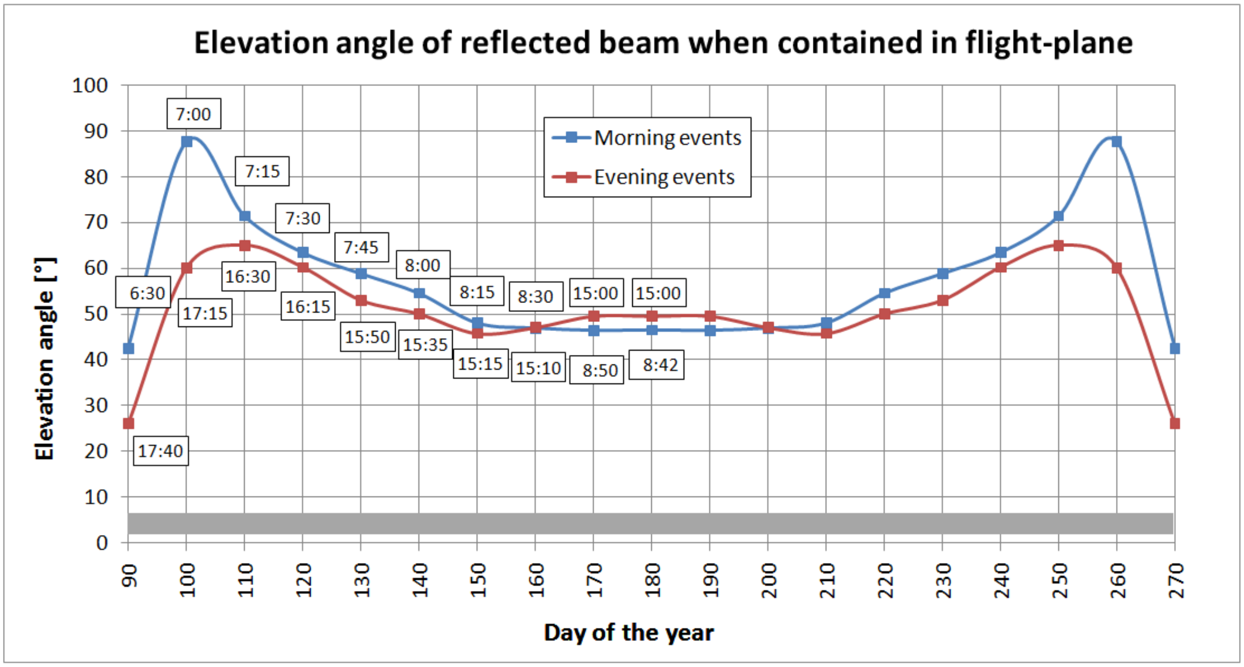



*Fig 21.- One year results for elevation angles of reflected beam when contained in the flight plane. For the six month period from October to March the reflected beam is never contained in the flight-plane.*

# 4 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected, but this might produce some glint to KVPs. For this Project, it is considered that airplanes landing at or taking-off from Calexico airport might be exposed to glint.

To determine the glint risk, a geometric analysis is done for both scenarios: Fixed tilt PV modules and Horizontal Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes (that is 35040 points). All mathematical expressions hereby described are implemented in a computer routine.

In the case of fixed tilt PV fields it has been demonstrated that, in the few cases when there is some risk of glint by PV modules, the airplane will also be directly facing the sun disk, so it can be concluded that glint from PV modules will not have any relevant effect on airplanes' visibility, nor deteriorate the actual approaching or launching flight conditions.

If the PV plant is built with horizontal axis tracking technology, the eventual reflected beam would have a high elevation angle (that is, pointing upwards), so no interference with approaching or launching airplanes from Calexico airport will ever occur.

The same conclusions can be extended to other tracking technologies (single inclined axis or double axis trackers). With these devices, the tracking efficiency is higher than with horizontal axis trackers, therefore the incident angle is even lower, and the reflected beam will be pointing the sun disk more closely. Risk for glint when landing of launching might theoretically occur only at low sun elevation angles (i.e., sunrise or sunset); however, during these particular hours the backtracking technology modifies the tracking algorithm to avoid mutual shading thus re-orientating the reflected beams upwards, far from the flight path.

It is concluded that this Project will not have any relevant glint effect for airplanes landing at or taking-off from Calexico airport. This is also applicable regardless of whether the Project is built in one, two or more phases.

# APPENDIX H

## Visualization Study

# Visualization Study

# Calexico Solar Farm II

Visualizations by

modative

Design
Develop
Build


Final design and location/route may be revised prior to issuance of permits

Viewshed Locations

**Calexico Solar Farm II (89MA)**

Key Plan

**date:** 7/15/11
**project:** 89MA

KEY

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Anza Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing

Proposed

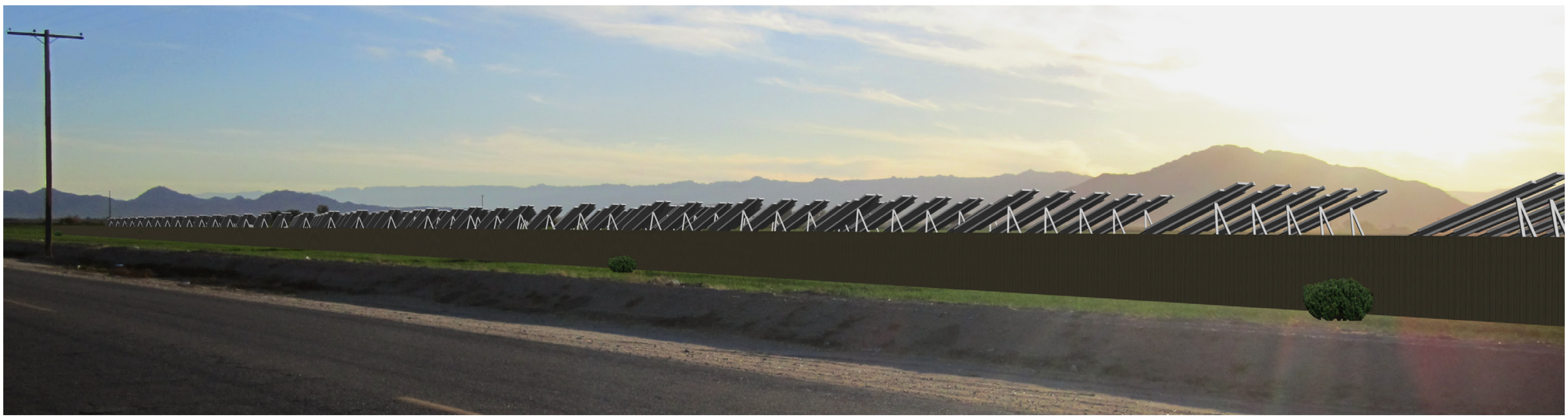
Final design and location/route may be revised prior to issuance of permits

Looking South-East Along Weed Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing



Proposed

Final design and location/route may be revised prior to issuance of permits

Looking South-West Along Ferrel Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Highway 98

## Calexico Solar Farm II (89MA)

**date:** 7/15/11
**project:** 89MA

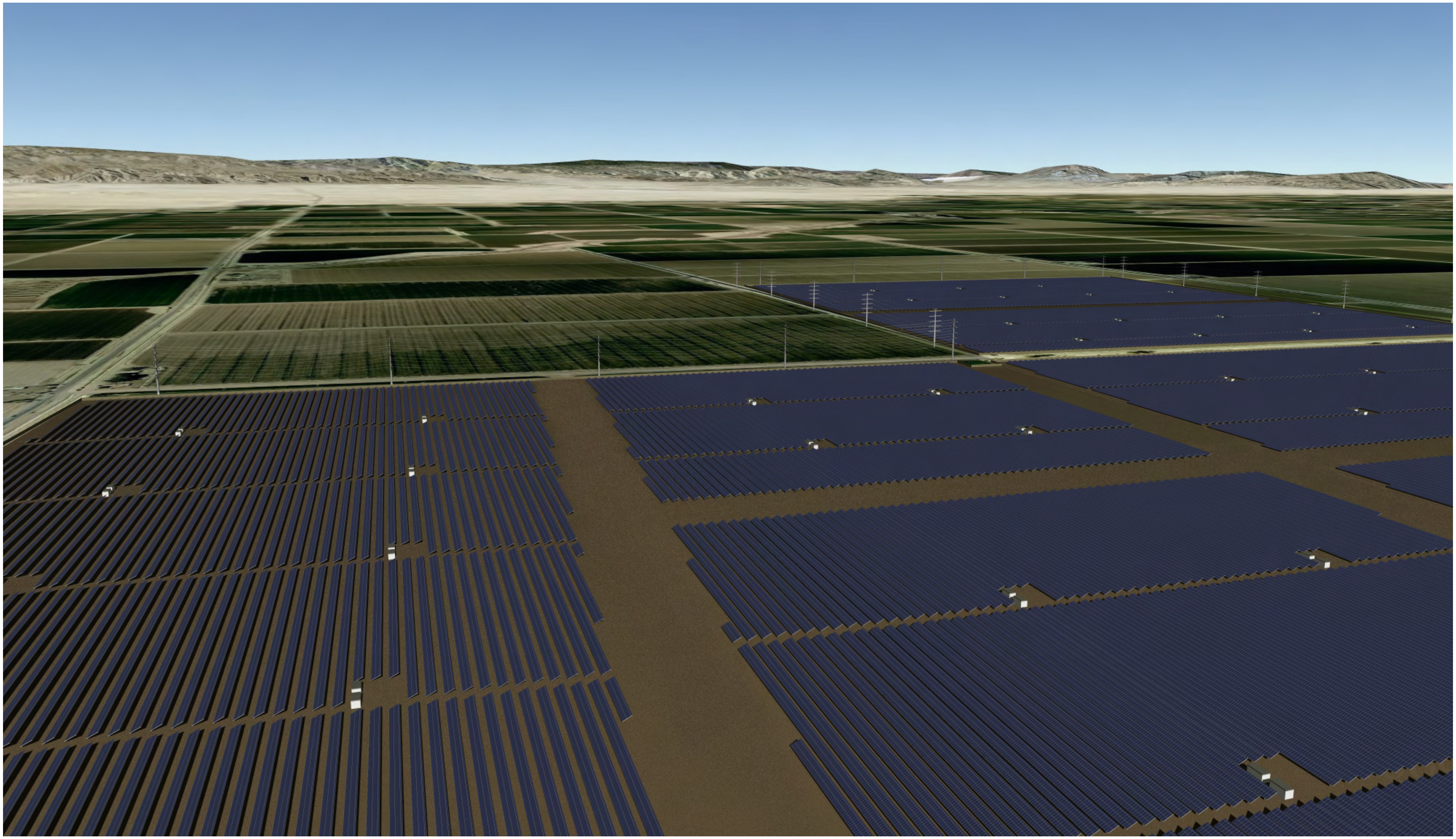
Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA



Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

# APPENDIX F

## Glare Analysis for Ground Traffic

April 11, 2011

Good Company
65 Centennial Loop, Suite B
Eugene, Oregon 97401

Mr. Thomas Buttgenbach
89MA 8ME LLC
10100 Santa Monica Blvd, Suite 300
Los Angeles, CA 90067

Dear Mr. Thomas Buttgenbach:

The purpose of this technical memo is to augment the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report. *The Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report analyzed the 89MA project as being constructed in one phase and under one conditional use permit. However after completing the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report, the project's construction plan was modified to reflect a second conditional use permit that would allow the project to be constructed in more than one phase. We have reviewed and analyzed this modification and have determined that the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report remain unchanged. In other words, the development of the project in more than one phase or CUP does not change the conclusions in the *Potential Impacts from Reflection of Proposed Calexico Solar Farm II* report. Please call me if you have any questions.

Joshua Skov

Principal, Good Company

# Potential Impacts from Reflection of Proposed Calexico Solar Farm II

Draft Date: April 14, 2011

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**KEY FINDINGS**

- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection above the nearby buildings and ground-traffic corridors.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Calexico Solar Farm II, which is located 1.5 miles west of Calexico in Imperial County, California. The project site is comprised of four parcels of land with a total area of 1,477 acres. See Appendix A for aerial photographs of the site.

The proposed project is a ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the proposed Calexico Solar Farm II on nearby roads and buildings. The reflection impacts on aircraft using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

## Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules.

In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

---

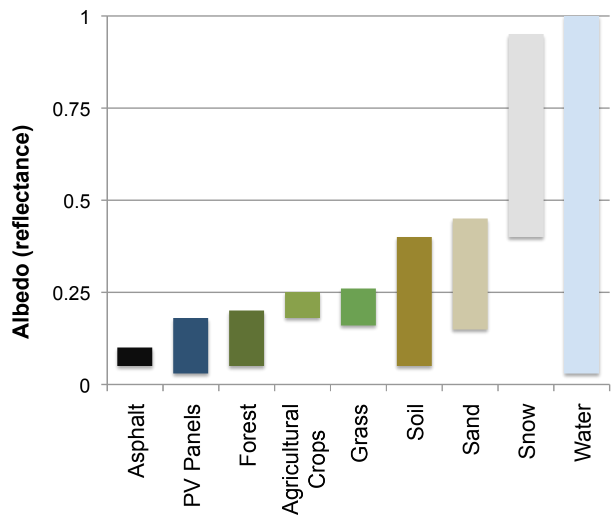
[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.

[2] Ibid.

## Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around 0.10.[3] By comparison, sand has an albedo between 0.15 and 0.45 and agricultural vegetation has an albedo between 0.18 and 0.25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

**Figure 1:** Albedo comparison for various surfaces.




## Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

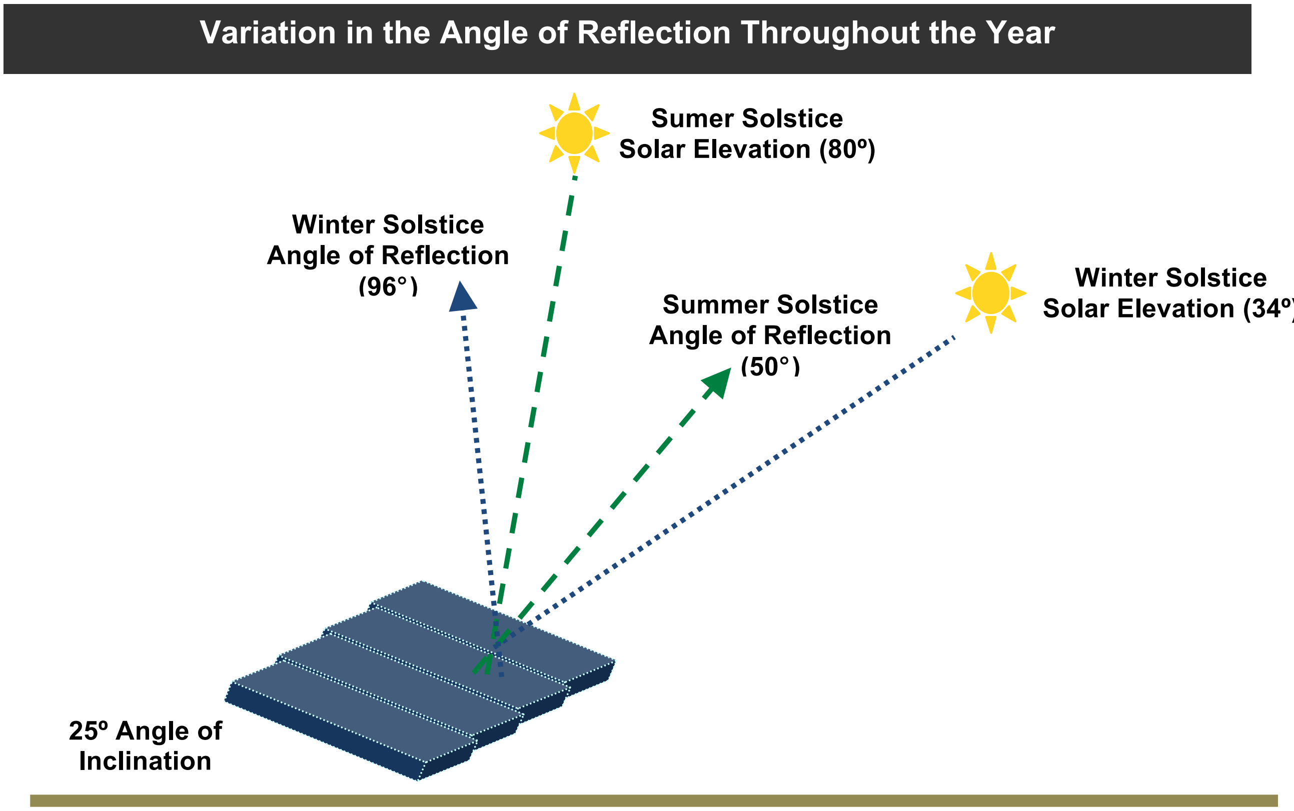
The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs midday on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 2 below). The potential impact at that moment is the best proxy for maximum impact overall.

During summer solstice at the proposed project's latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is unlikely that vehicles traveling on nearby roads or buildings south of the project site would be adversely affected by a direct reflection of sunlight from this angle. Continue reading this section for more details.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed project's latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.39 degrees north.

**Figure 2:** The range of the sun's angle-of-reflection depending on the time of year.




The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 20 feet (the approximate distance from the southern edge of the Calexico Solar Farm II project, Parcel II, to the edge of Highway 98), the height of the reflected sunlight from the array would be nearly 24 feet in elevation, well above the California truck height limit of 14 feet. It is important to note that the other roads in the immediate vicinity of the proposed arrays are not major transportation corridors and as such are not expected to support significant passenger or commercial traffic. Highway 98 also travels east west and thus, vehicles on the road would not be directly facing the solar arrays that are north of the highway. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (and any indirect reflection).

The built structures closest to the Calexico Solar Farm II project site are a cluster of buildings (appearing to be barns and storage buildings), 30 feet south from the nearest edge of the Parcel III array. At this distance, the height of direct reflection is 36 feet. There is a residential neighborhood on the western edge of Mexicali, Mexico. These homes are 0.45 miles due south from the southern edge of Parcel III. At this distance, the elevation of direct glare would be over 0.5 miles high, the height of a 188-story building[6].

[6] This number of floors assumes a height of 15 feet per floor.

**Figure 3:** Map of the points listed in Figure 4 and the "on the ground" distance from each point to the array.

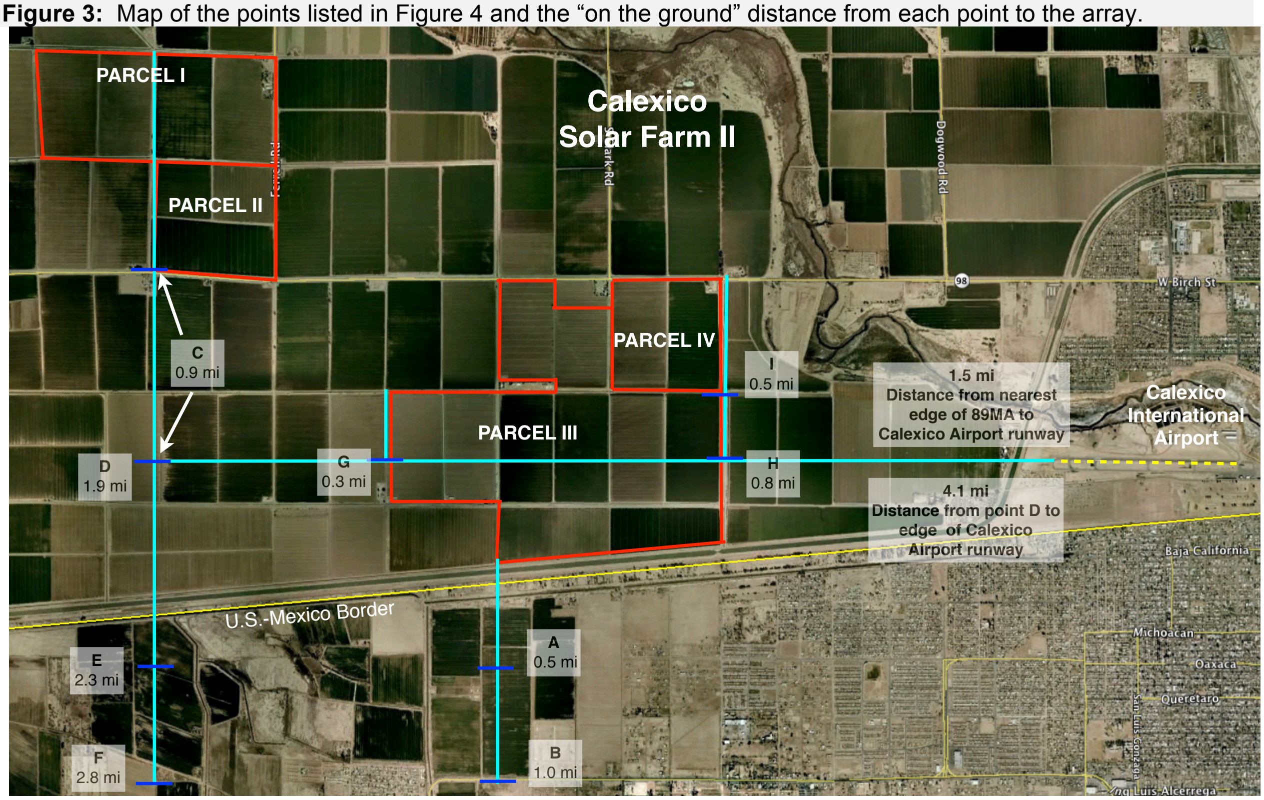



**Figure 4:** Elevation of direct reflection for the points shown on Figure 3.

| Point on Figure 3 | Elevation of Direct Reflection | |
|---|---|---|
| | miles | feet |
| A | 0.60 | 3,147 |
| B | 1.19 | 6,294 |
| C | 1.07 | 5,665 |
| D | 2.26 | 11,954 |
| E | 2.74 | 14,472 |
| F | 3.34 | 17,619 |
| G | 0.36 | 1,890 |
| H | 0.60 | 3,147 |
| I | 0.95 | 5,032 |

## Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[7]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[8]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (and any indirect reflection).

## Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array the greatest potential for a low angle of reflection, that might impact the built environment, occurs midday on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At midday on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

---

[7] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see "Panache Valley Solar Farm Project Glint and Glare Study" (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and "Topaz Solar Farm Reflection Study" (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).

[8] TrinaSolar. "Reflection Coefficient of Trina Solar Modules." Personal communication with Thomas Houghton, June 30, 2010.

## Appendix A: Glare Analysis Explanation

### Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[9] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

**Figure 8:** Angle of direct reflection on summer solstice (June 21).

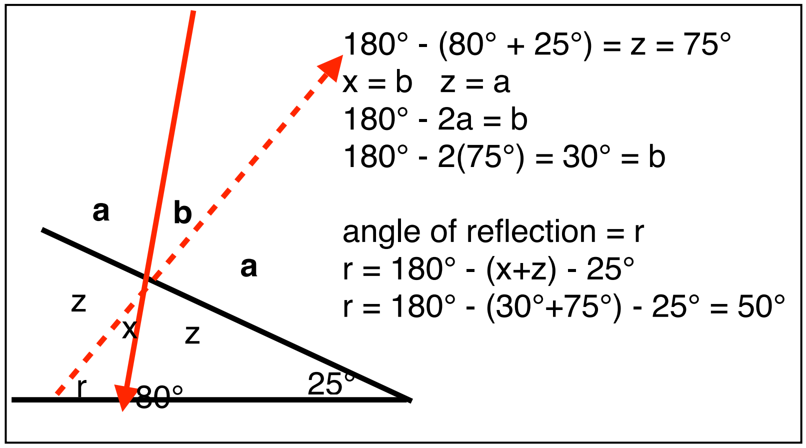
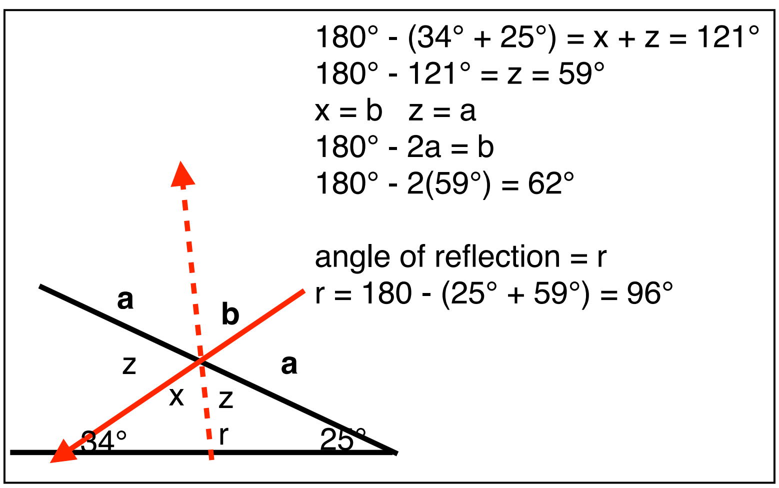



Figure 8 to the right depicts this reflection. All angles within a triangle summed equal 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

**Figure 9:** Angle of direct reflection on winter solstice (Dec. 21).



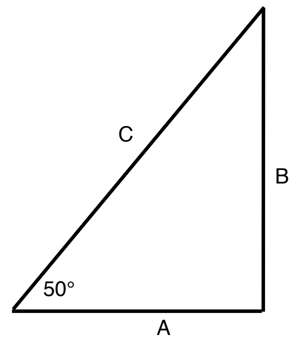

Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point during winter solstice on December 21st (see Figure 9, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[9] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

## Determining the Height of Reflection

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Calexico Solar Farm II. Figure 10 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

**Figure 10:** Calculation to determine direct reflection.

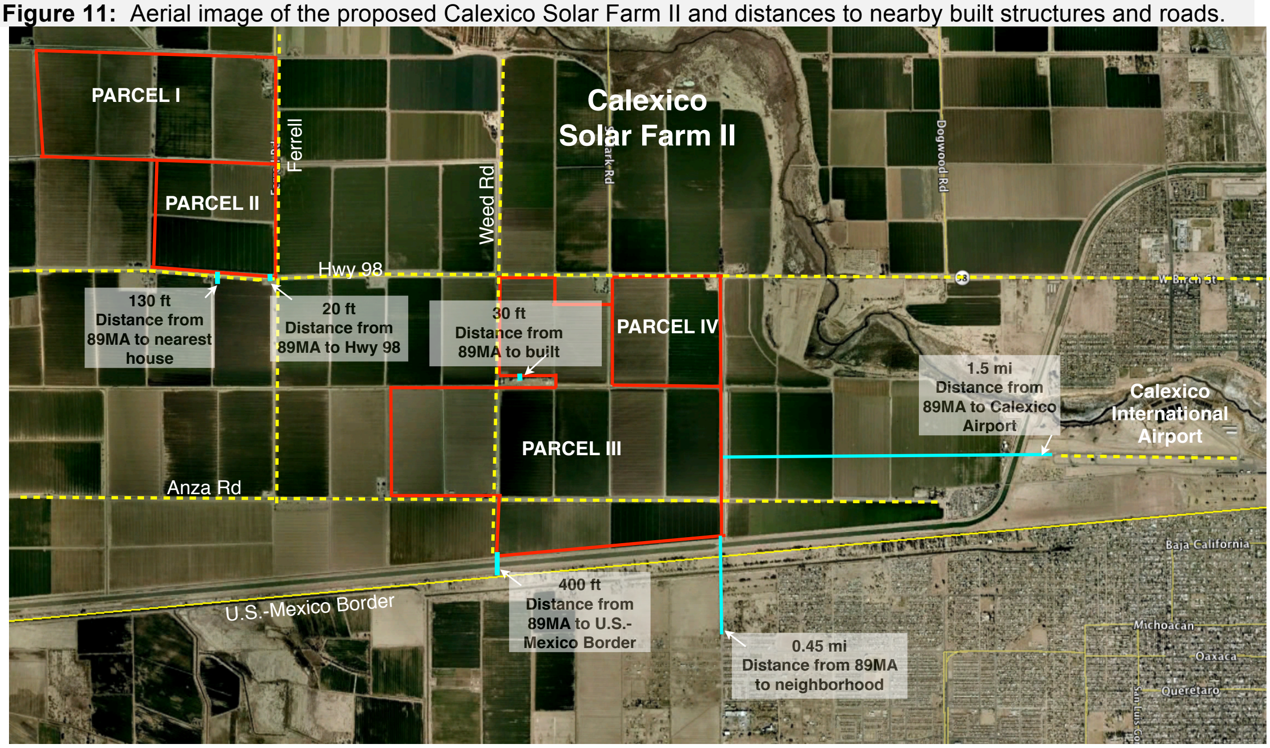



$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 11 is an aerial picture of the sited Calexico Solar Farm II from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico border (yellow line) as well as the four portions of the project which serve as the boundaries for the panel arrays in this project. Figure 11 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 11 describe the height of the direct reflection at the various distances shown by the blue lines.

**Figure 11:** Aerial image of the proposed Calexico Solar Farm II and distances to nearby built structures and roads.




- At 20 feet from the solar panels the height of the reflection is already at 24 feet.
- At 30 feet from the solar panels the height of the reflection is at 35.8 feet or higher (depending on the time of year).
- At 130 feet from the solar panels the height of the reflection is 155 feet or higher.
- At 400 feet from the solar panels the height of the reflection is 477 feet or higher.

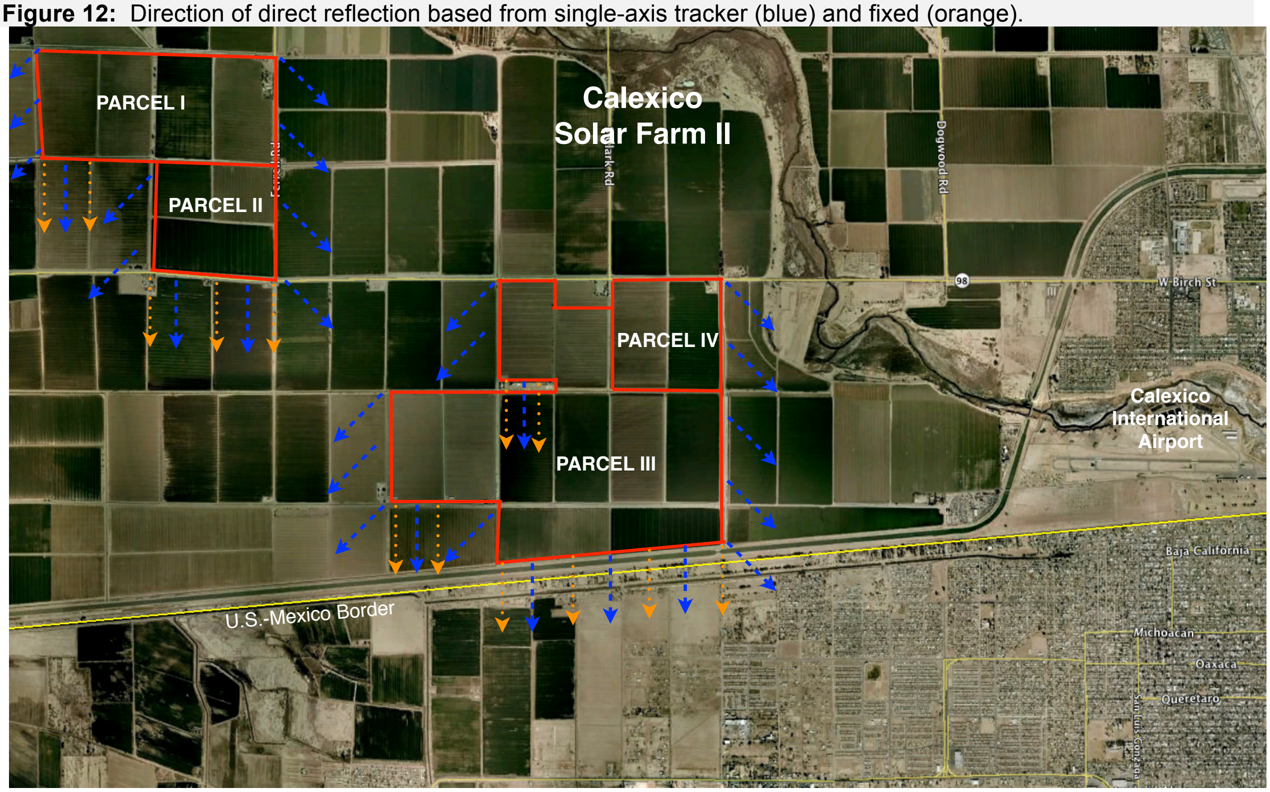
• At 0.45 miles from the solar panels the height of the reflection is 0.54 miles (2,832 feet) or higher.

• See the Reflectivity Analysis conducted by Aztec Engineering for details on potential impacts to aircraft utilizing Calexico International Airport.

## Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

**Figure 12:** Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).



# APPENDIX G

## Glare Analysis for Air Traffic

# CALEXICO Solar Farm II (89MA 8ME, LCC)

# REFLECTIVITY ANALYSIS

REVISION INDEX

| Page/Reason | REV | Date | PROD | CHECK | APRV |
|---|---|---|---|---|---|
| All | 0 | 04/13/2010 | JDL | JDL | JDL |
| | | | | | |
| | | | | | |
| | | | | | |

## Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to a series of photovoltaic (PV) power plants being developed by 89MA 8ME, LLC. Project location is nearby the Calexico airport in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the corresponding airport runway if reflected sun light beam intersects the approaching flight path.

Fig. 1 shows the location of the future PV plant relative to Calexico airport.

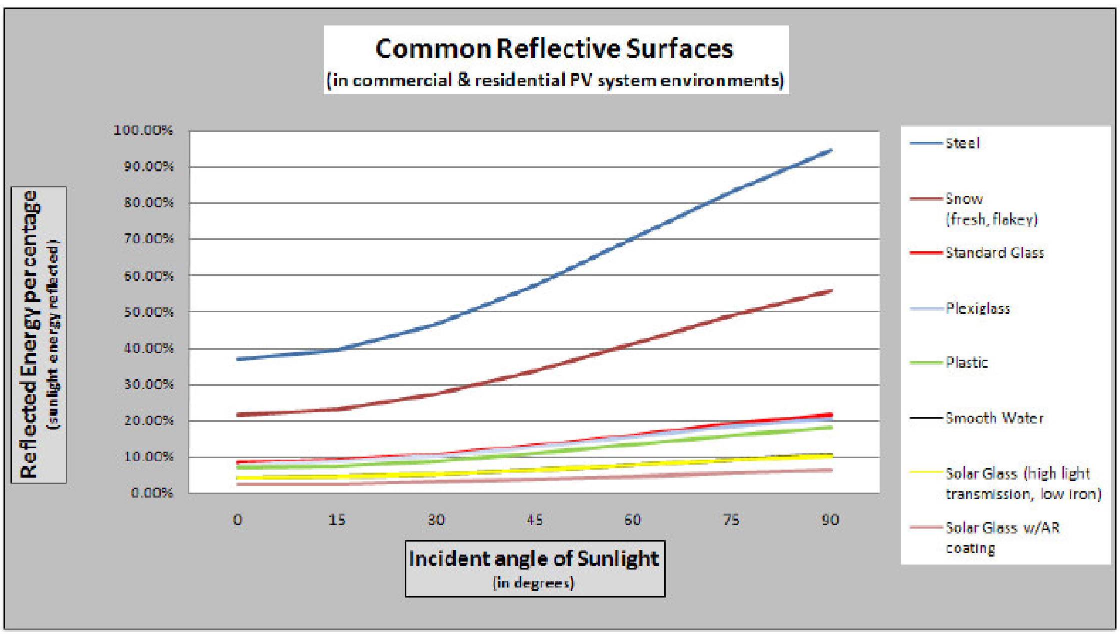

*Fig 1.- Location of PV Project and Calexico airport*

To evaluate the risk of direct sun light reflection events a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer direct reflection.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of the study:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the

reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and have negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules., for instance agricultural environment has higher Glare effect than PV modules.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to the airport runway.

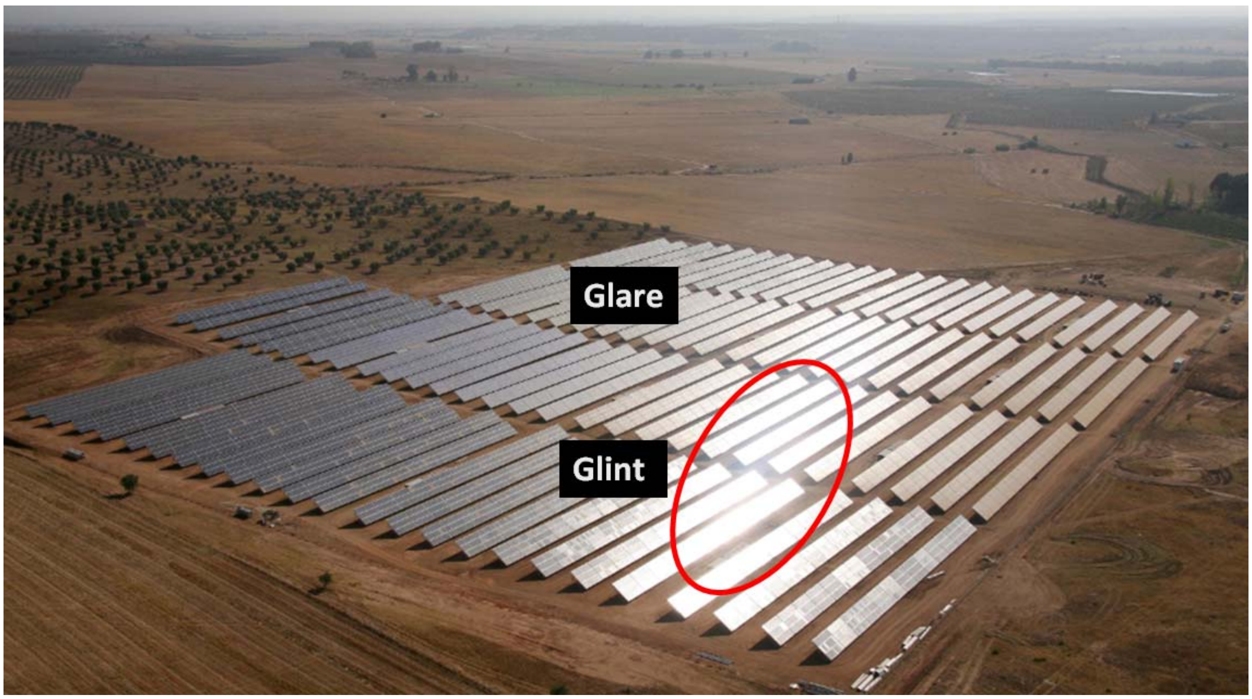



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Mathematical analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the future PV plant location, as shown in Fig. 3 below:


*Fig 3 .- Reference coordinate system*

Next image shows a 3D rendering of the future Project

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

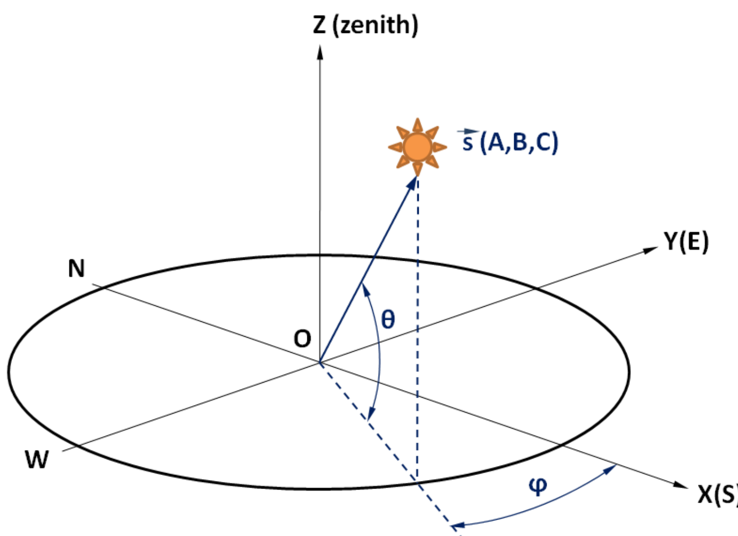



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta \ \cos\varphi$$
$$B = -\cos\theta \ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:
Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, $1^{st}$ is i=1; February, $1^{st}$ is i = 32,… until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc).
As an example, the calculated values for azimuth and elevation angles for the equinox (March, $21^{st}$, i = 80) are plotted in function of the hour of the day in the next graph:

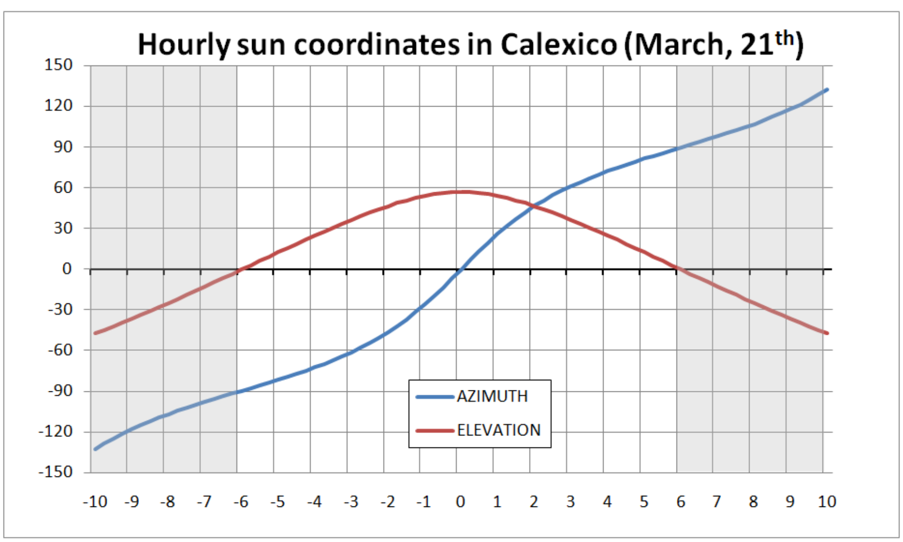



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

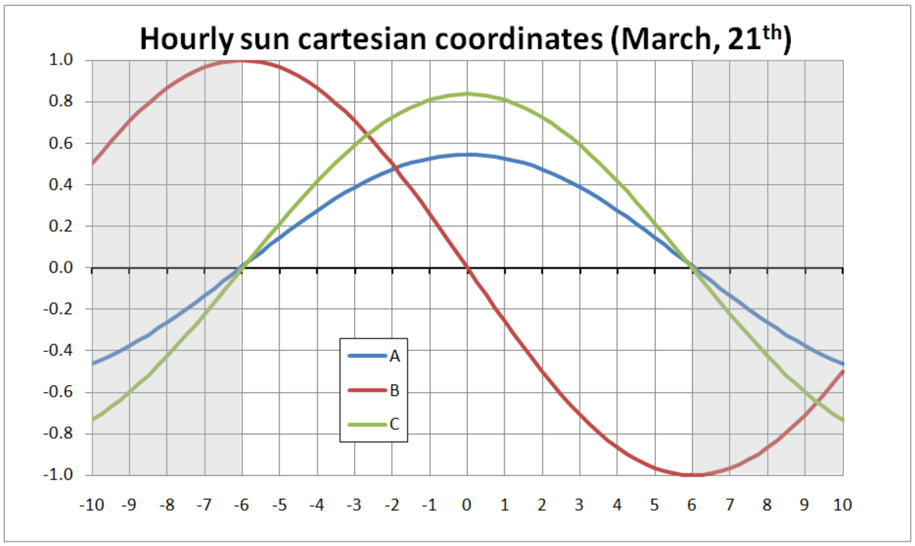



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located at the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

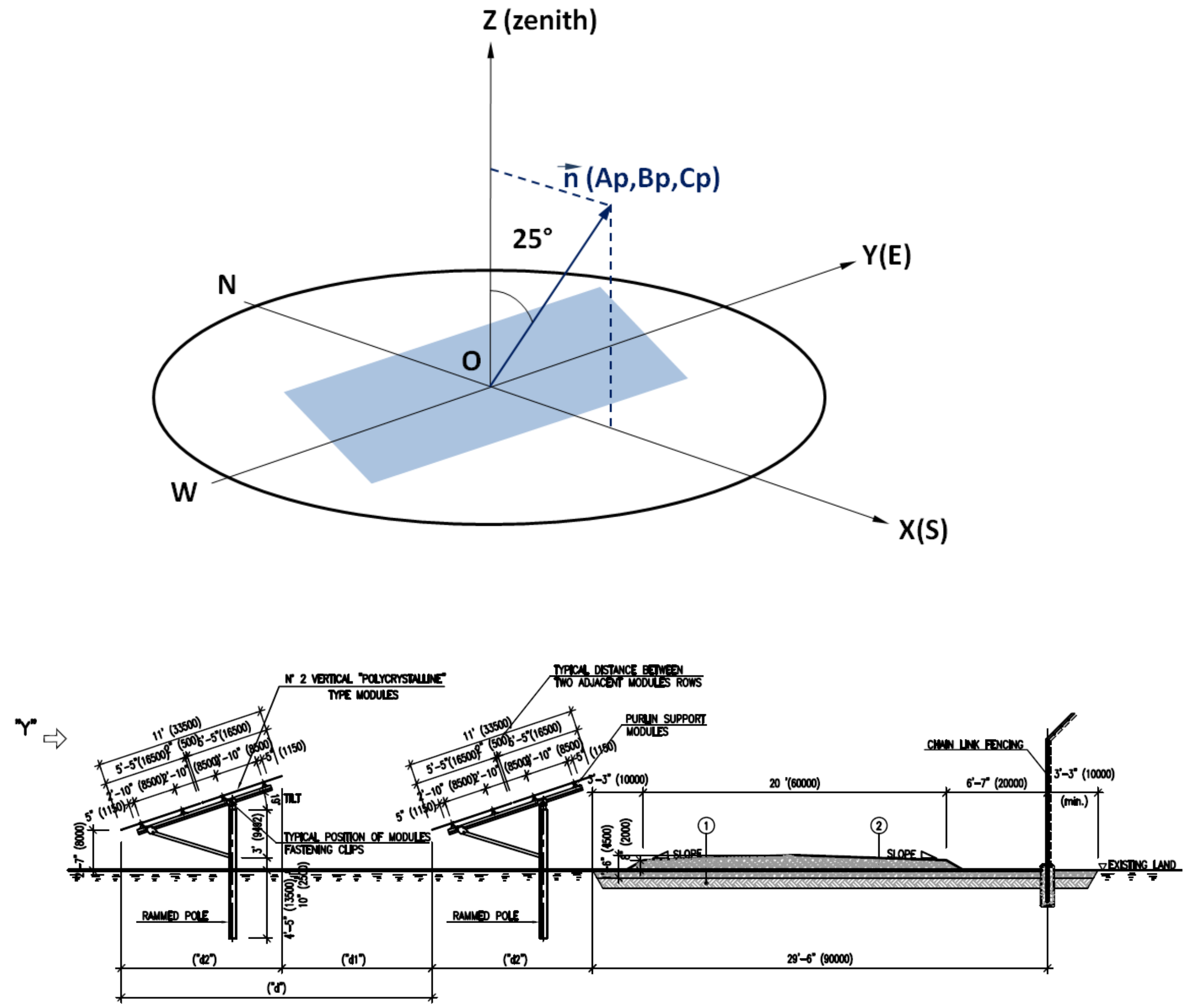



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:

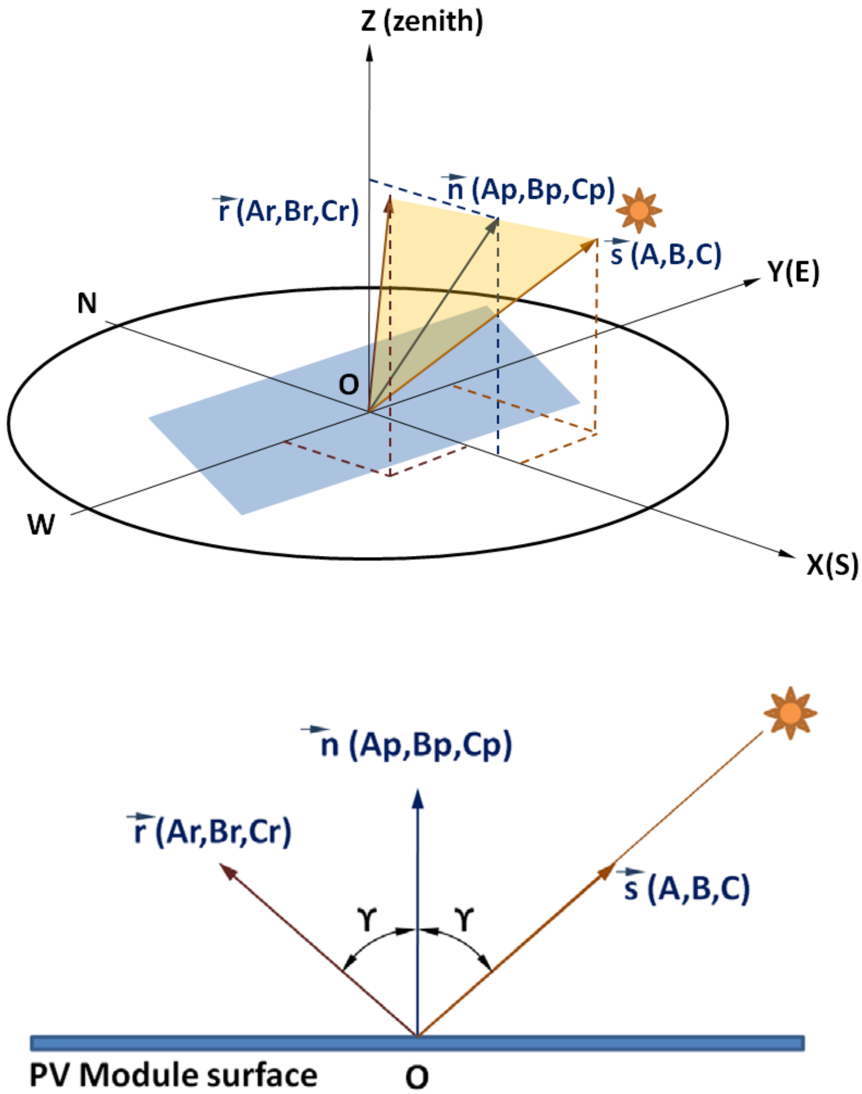



*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\ \vec{n} - \ \vec{s}$$

and its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\ A_p - A$$
$$B_r = 2\ \cos\gamma\ B_p - B$$
$$C_r = 2\ \cos\gamma\ C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

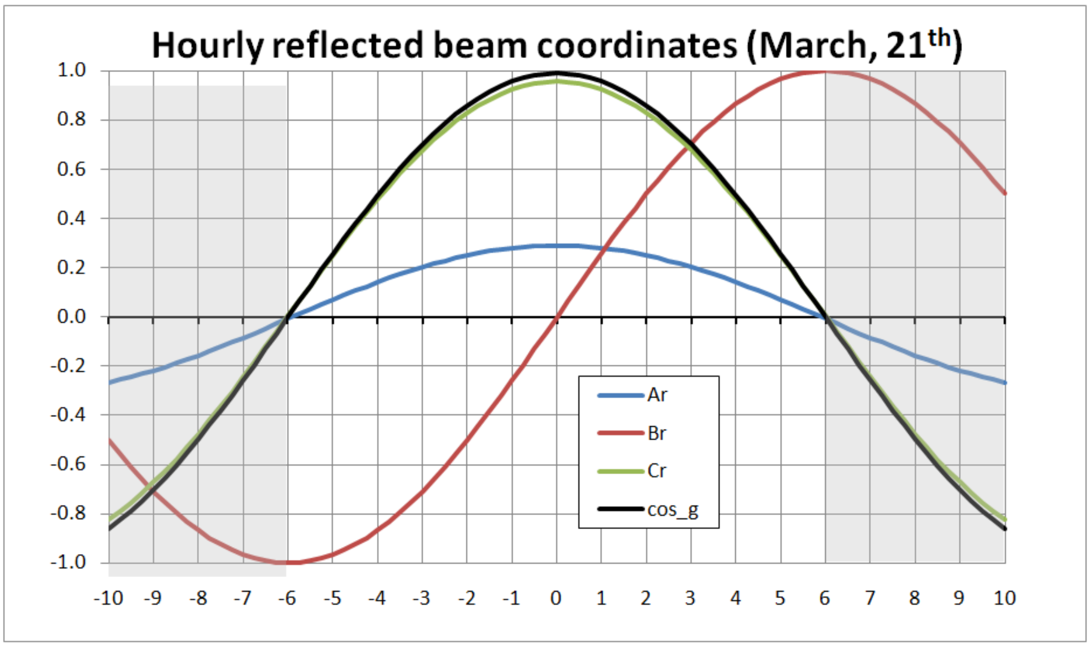



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity at Calexico runway (fixed systems)

To define the location of relevant KVP it is hereby assumed that the approaching airplane follows a straight line contained in a vertical plane (the “flight plane”) that also contains the runway axis (Fig. 10).

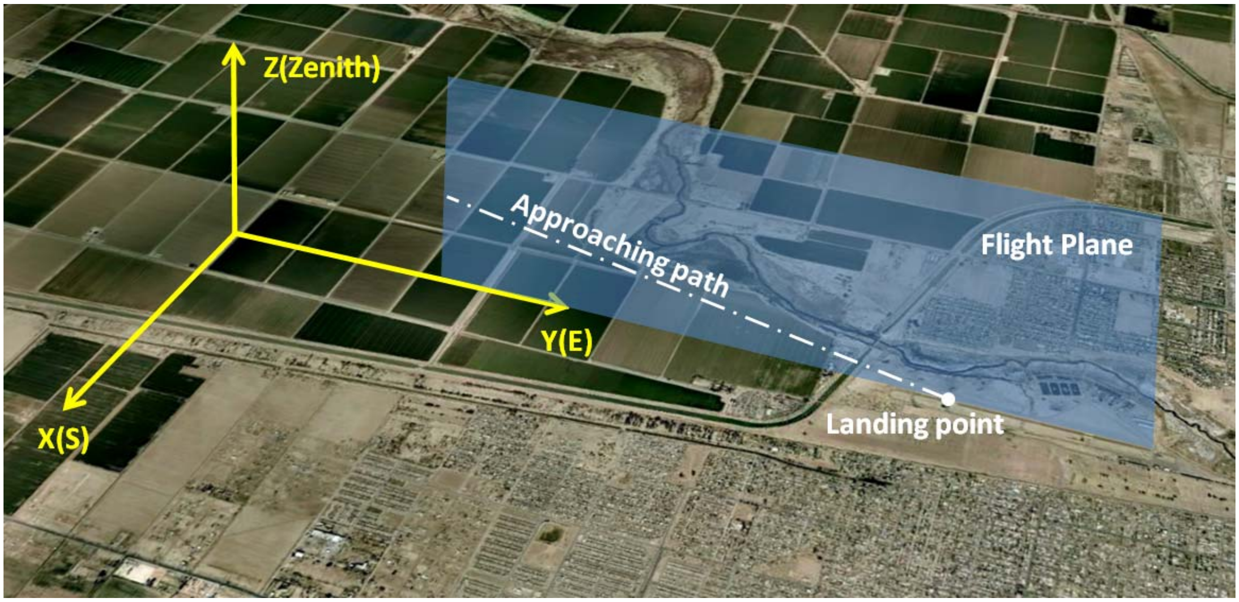



*Fig 10.- Geometry of approaching path*

The vertical flight plane, containing the approaching path, is defined by the following equation in the reference Cartesian axis system:

$$\Pi \equiv 0.9997\ x - 0.0239\ y = 0$$

The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

Runway azimut is 88.63°. Cartesian coordinates for any reflected beam r = (Ar, Br, Cr), if contained in the flight plane, shall satisfy the following condition (beam azimuth):

$$\frac{B_r}{A_r} = \tan\ 88.63° = 41.814$$

The angle between the horizontal plane and the reflected vector (reflection elevation angle) is given by

$$\tan\theta_r = \frac{C_r}{\sqrt{A_r^2 + B_r^2}}$$

Fig. 14 shows the hourly evolution of the above functions for a sample day (March, 2$^{nd}$)

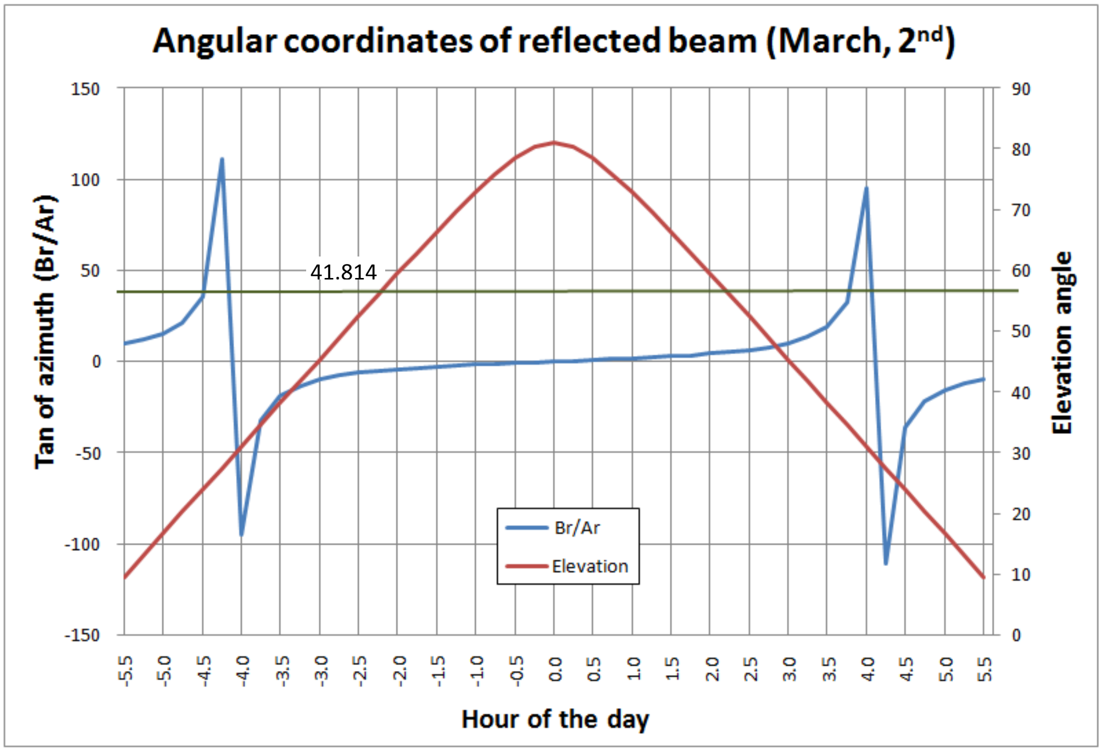
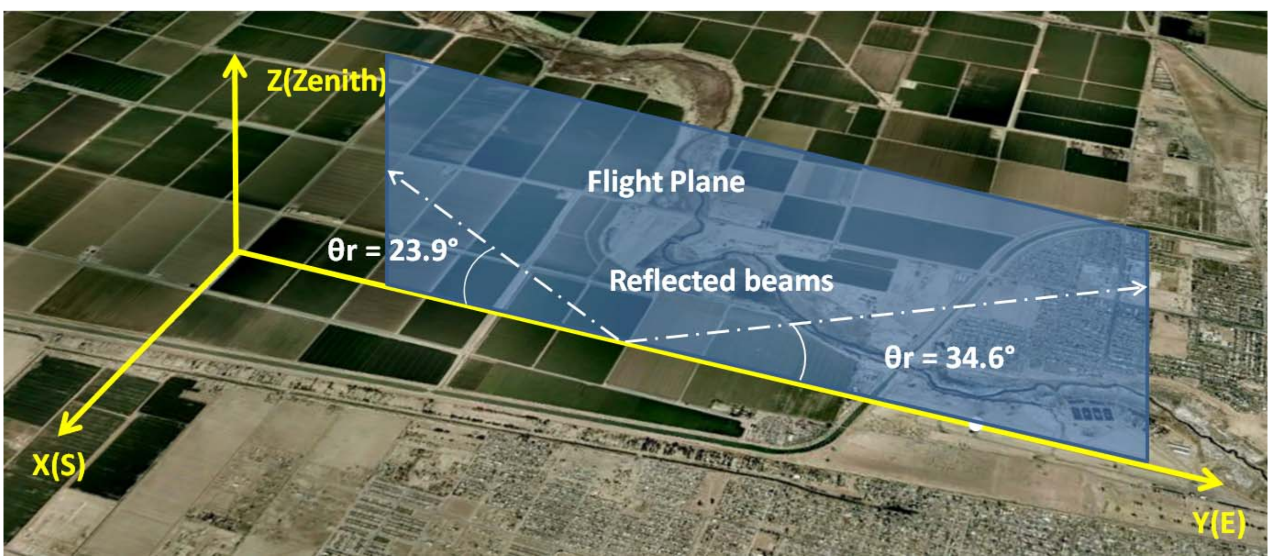



*Fig 14.- Angular coordinates of reflected beam (March, 2nd)*

It can be seen that the reflected beam will be contained in the flight plane at 07:30h (after sunrise) and at 15:45h (before sunset). The reflected beam will be pointing upwards with an angle of 23.9° and 34.6° respectively.




Obviously, the reflection held at 07:30 would affect airplanes landing Calexico from West, while the reflection held at 15:45h would afect airplanes landing or launching from East. In both cases, a long-term glint exposure would only occur if the airplanes were landing at the same particular angles (i.e., 23.9° and 34.6° respectively). It should be noted that normal landing angles are within the range of 3° and 6°, so in this particular day no risk of prolonged glint is possible.

The same procedure is repeated for all days in a year. Results in Fig.15 shows the elevation angle of the reflected beam in function of the day, whenever the in-plane condition occurs. Bandwith between estimated minimum and maximum airplane landing angles (3° and 6°) is superimposed :

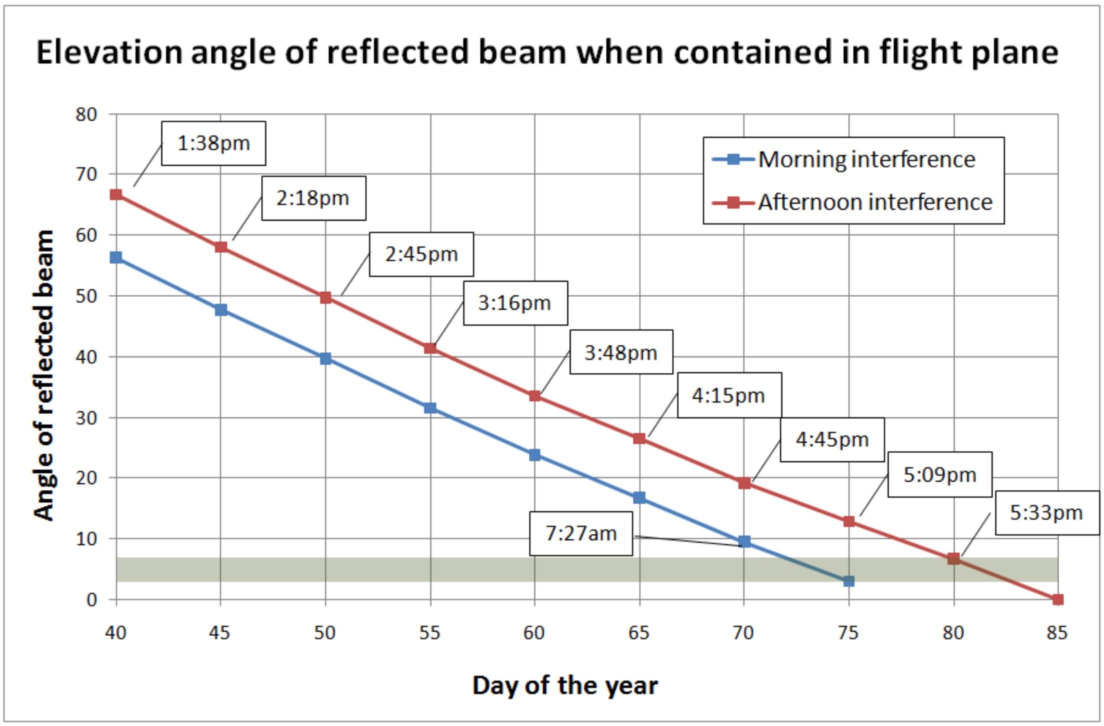



*Fig 15.- Reflected beam elevation angle and landing angles – Runway 29*

There are a few days in the year where there is an eventual risk of glint from the PV modules to landing airplanes. These particular days are 72 to 75 (2nd week of March - morning time) and 80 to 83 (3rd week of March - evening time). Because of yearly simmetry, the same occurs in mid-October.

Fig. 16 shows sun coordinates for a typical day in these periods (day 73). Interference with landing path occurs at around 07:37 hours, sun azimuth is -84° and elevation only 3°. Therefore airplanes reaching Calexico airport runway from the West end will have the sun disc just in front of them. It is considered that glint effect is neglegible when compared to direct sun light exposure, as in this case.

Similarly, planes landing or launching from the East at day (say) 82, will be facing the sun disc at sunset, and again the risk of glint is negligible when compared to the light intensity of direct sun.

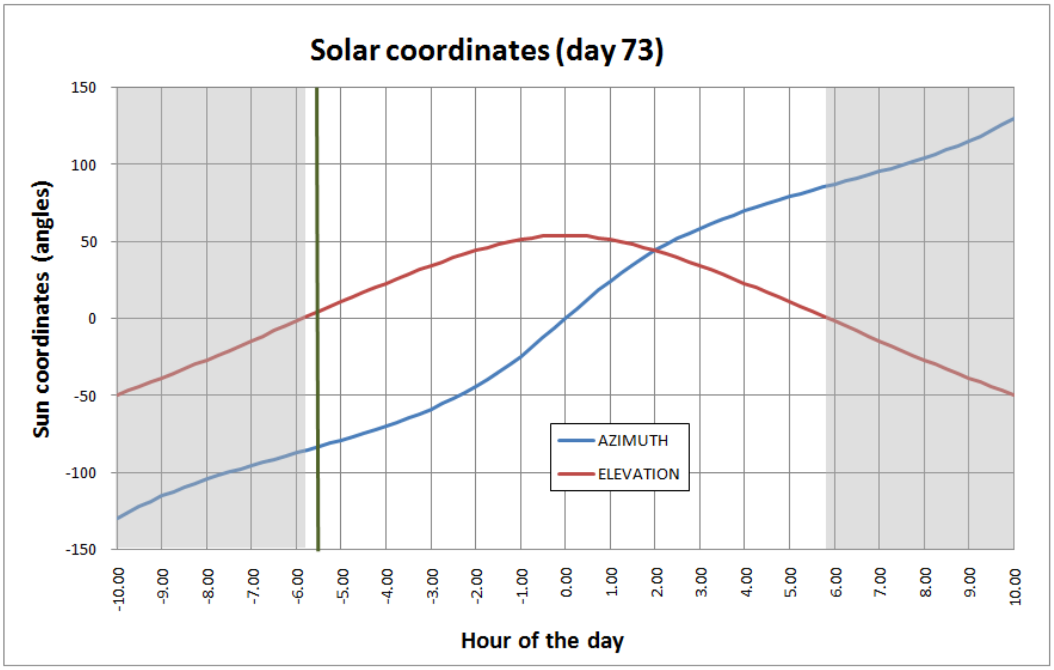
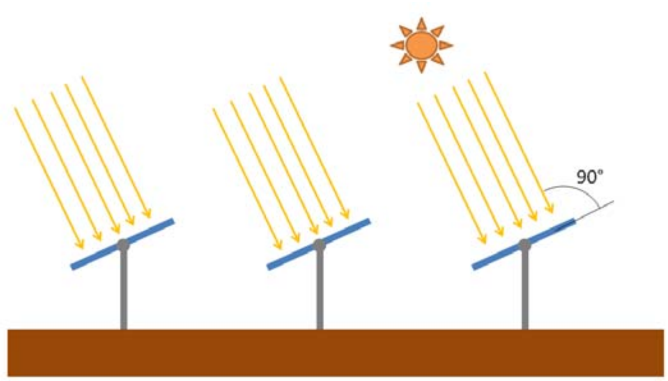



*Fig 16.- Sun postion for selected typical interference day – Green vertical line shows time of interference with airplane landing path.*

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.



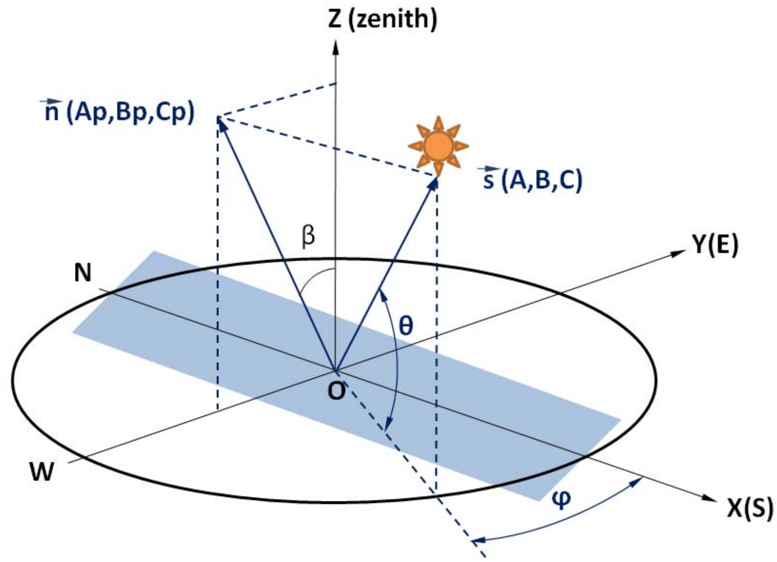



*Fig 17.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\ A_p + B\ B_p + C\ C_p$$

this can be written as

$$\cos\gamma = -B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\ (\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad \tan\beta = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

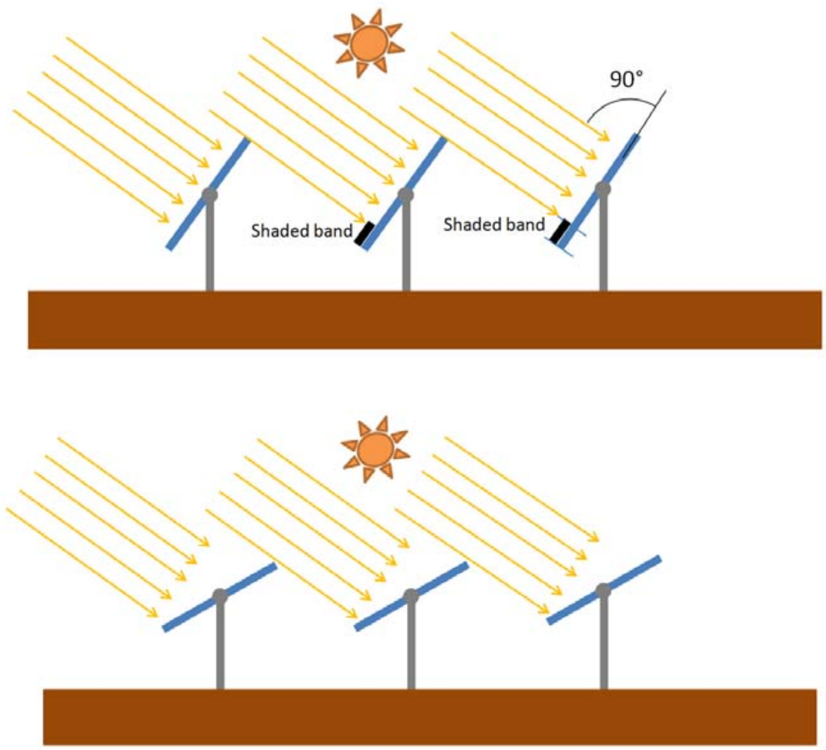



*Fig 18.- Above: Mutual shading without backtracking.*
*Below: Backtrackin corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons.

Fig. 19 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

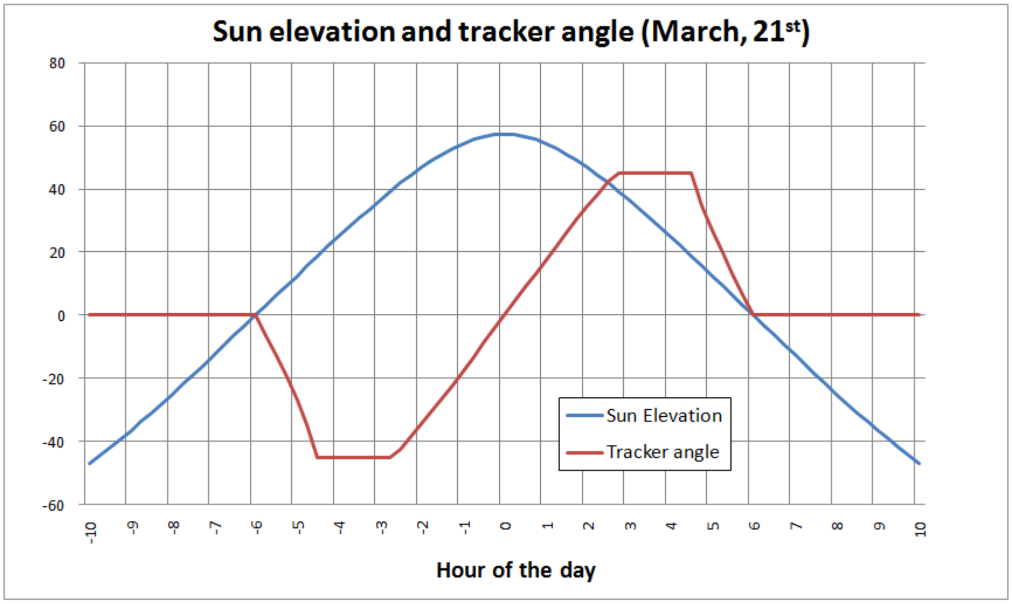



*Fig 19.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 20,

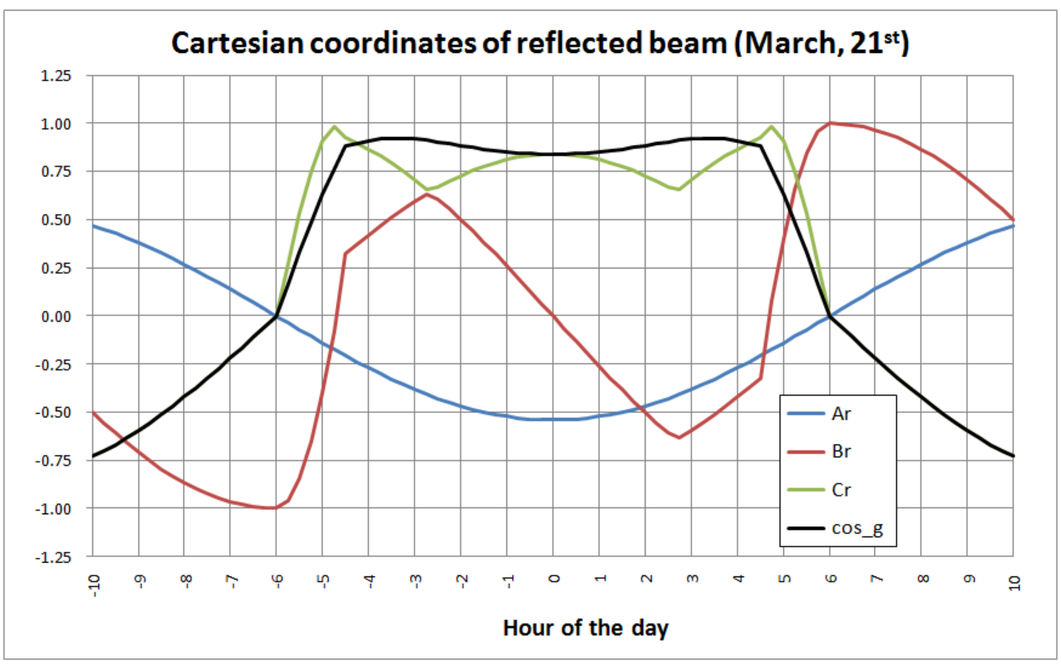



*Fig 20.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at Calexico

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

As an example, Fig. 21 shows the azimuth and elevation angle of the reflected beam. The green line defines the flight-plane azimuth condition for Calexico, thus the reflected beam will be contained in this particular plane at 8:45am and 3:00pm, but in both cases the beam elevation angle is well over 40°, so there is no risk for glint.

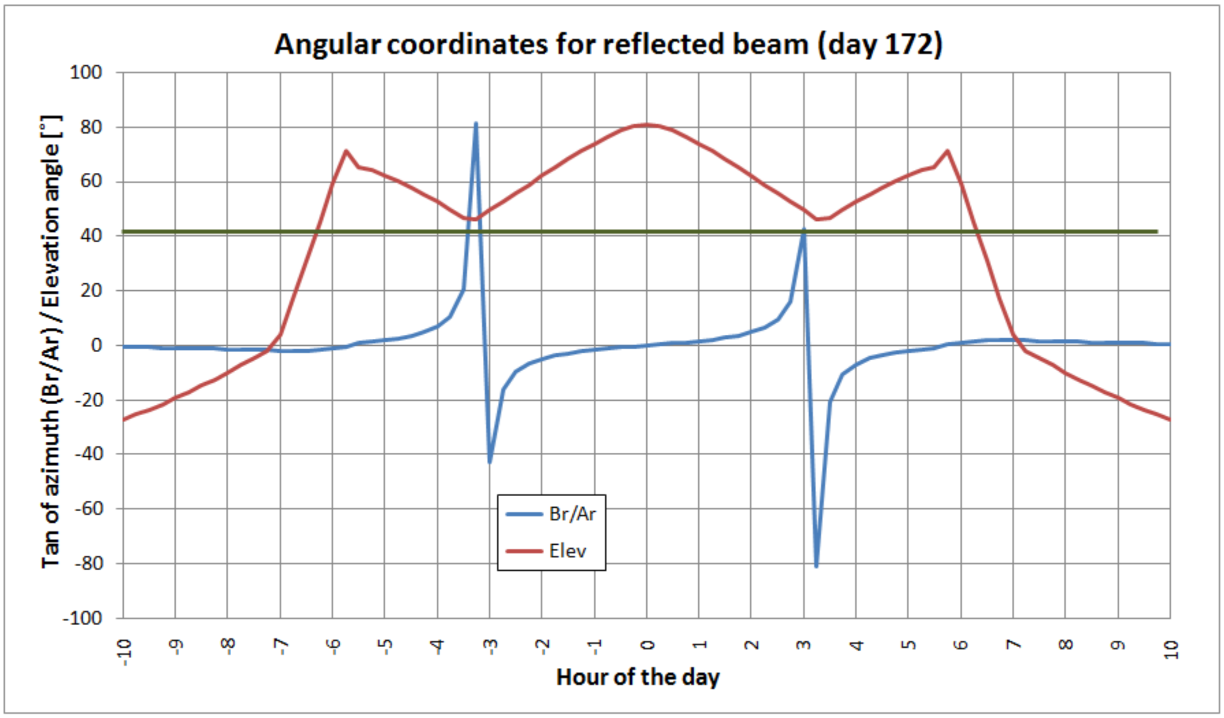



*Fig 21.- Angular coordinates for reflected beam (day 172)*

The same calculation is repeated for a complete year and results shown in Fig. 22.

It can be seen that whenever the reflected beam is contained in the flight-plane, its elevation angle is very far from the usual approaching or launching angles to the airport, so there is no risk of glint with trackers.

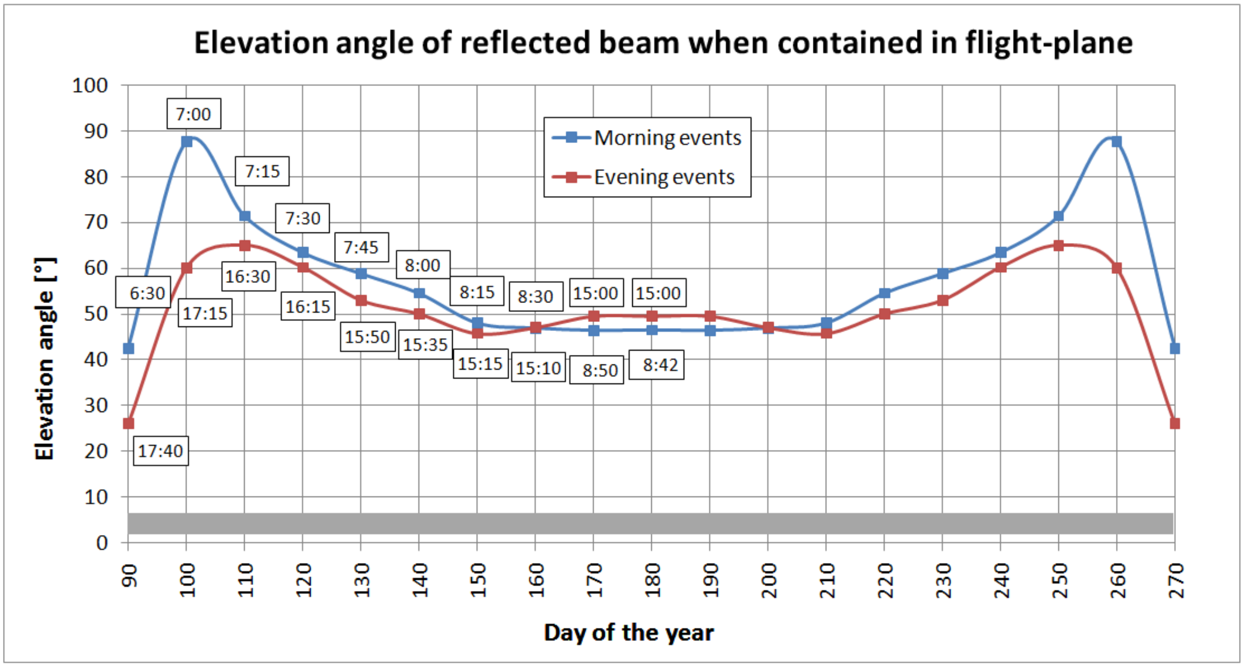



*Fig 21.- One year results for elevation angles of reflected beam when contained in the flight plane. For the six month period from October to March the reflected beam is never contained in the flight-plane.*

# 4 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected, but this might produce some glint to KVPs. For this Project, it is considered that airplanes landing at or taking-off from Calexico airport might be exposed to glint.

To determine the glint risk, a geometric analysis is done for both scenarios: Fixed tilt PV modules and Horizontal Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes (that is 35040 points). All mathematical expressions hereby described are implemented in a computer routine.

In the case of fixed tilt PV fields it has been demonstrated that, in the few cases when there is some risk of glint by PV modules, the airplane will also be directly facing the sun disk, so it can be concluded that glint from PV modules will not have any relevant effect on airplanes' visibility, nor deteriorate the actual approaching or launching flight conditions.

If the PV plant is built with horizontal axis tracking technology, the eventual reflected beam would have a high elevation angle (that is, pointing upwards), so no interference with approaching or launching airplanes from Calexico airport will ever occur.

The same conclusions can be extended to other tracking technologies (single inclined axis or double axis trackers). With these devices, the tracking efficiency is higher than with horizontal axis trackers, therefore the incident angle is even lower, and the reflected beam will be pointing the sun disk more closely. Risk for glint when landing of launching might theoretically occur only at low sun elevation angles (i.e., sunrise or sunset); however, during these particular hours the backtracking technology modifies the tracking algorithm to avoid mutual shading thus re-orientating the reflected beams upwards, far from the flight path.

It is concluded that this Project will not have any relevant glint effect for airplanes landing at or taking-off from Calexico airport. This is also applicable regardless of whether the Project is built in one, two or more phases.

# APPENDIX H

## Visualization Study

# Visualization Study

# Calexico Solar Farm II

Visualizations by

modative

Design
Develop
Build


Final design and location/route may be revised prior to issuance of permits

Viewshed Locations

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Key Plan

KEY

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Anza Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing

Proposed

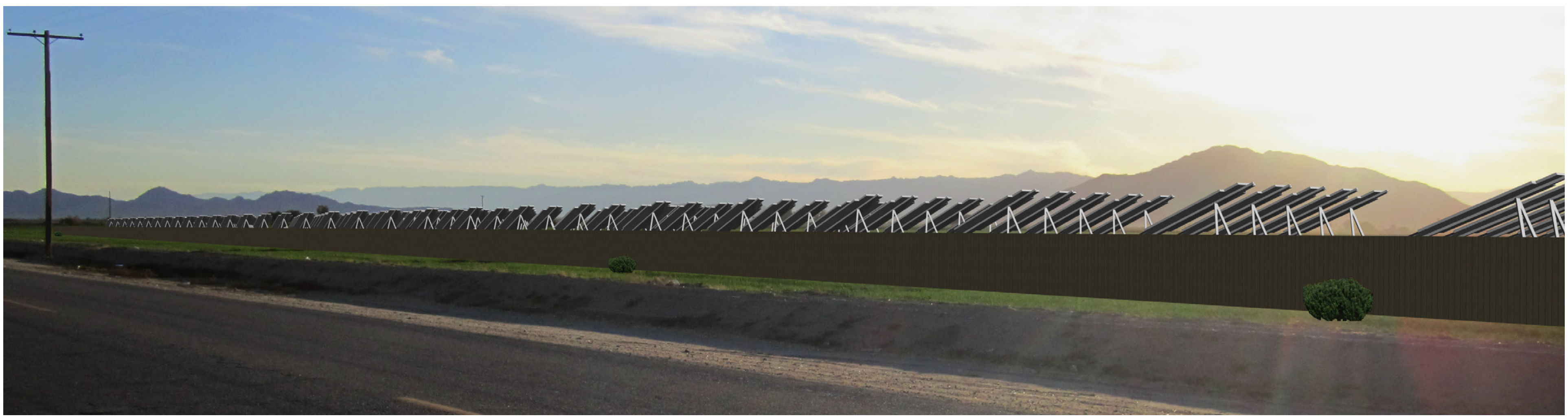
Final design and location/route may be revised prior to issuance of permits

Looking South-East Along Weed Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing



Proposed

Final design and location/route may be revised prior to issuance of permits

Looking South-West Along Ferrel Road

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Highway 98

**Calexico Solar Farm II (89MA)**

**date:** 7/15/11
**project:** 89MA

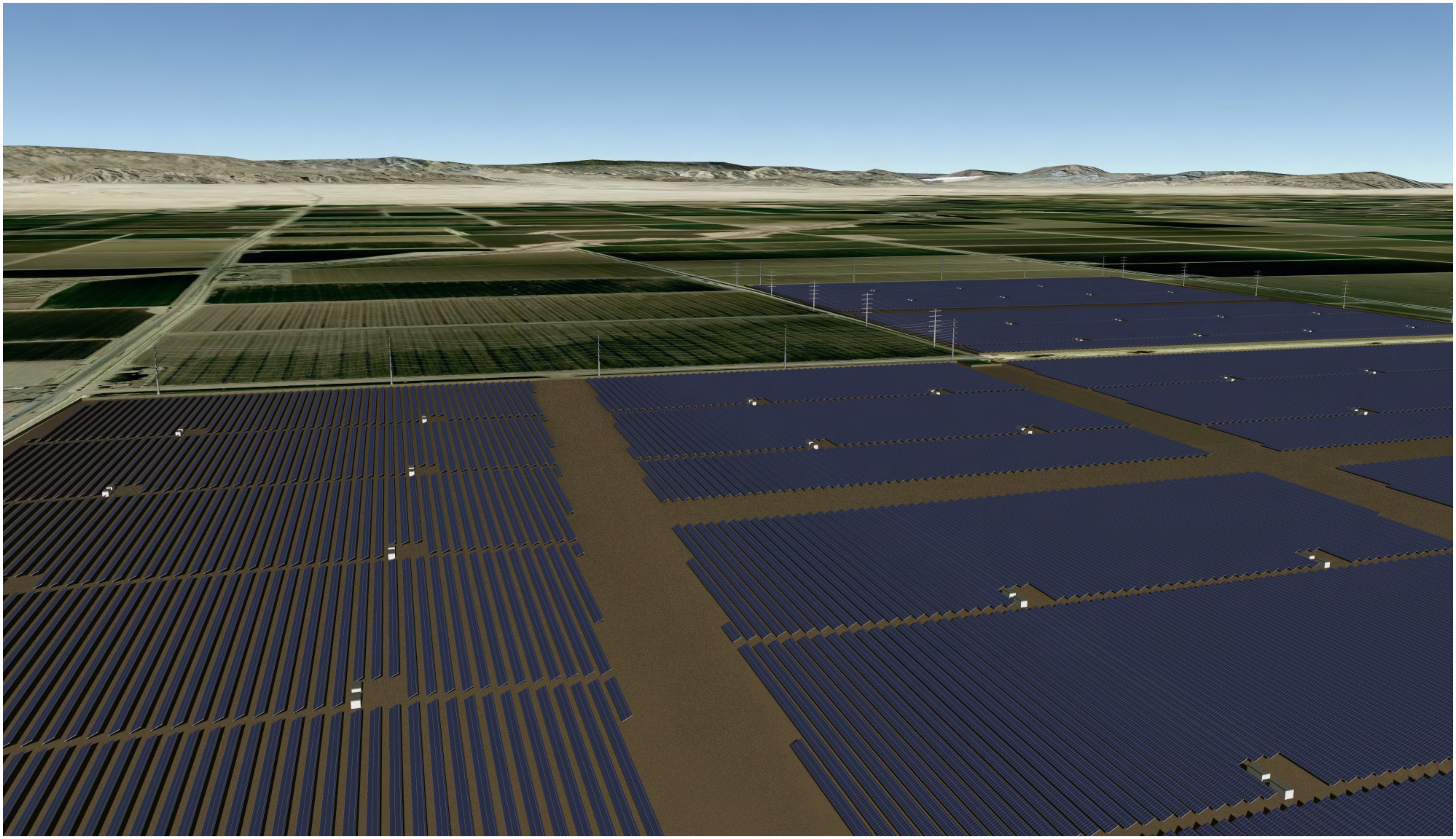
Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

## Calexico Solar Farm II (89MA)

**date:** 7/15/11
**project:** 89MA



Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

## Calexico Solar Farm II (89MA)

**date:** 7/15/11
**project:** 89MA

**Prepared for:**

8MinuteEnergy, LLC.
10100 Santa Monica Boulevard, Suite 300
Los Angeles, CA 90067

**Prepared by:**

AZTEC Engineering, Inc.
4561 East McDowell Road
Phoenix, AZ 85008
(602) 454-0402

# CALEXICO Solar Farm II - 89MA Project

# REFLECTIVITY ANALYSIS

REVISION INDEX

| Page/Reason | REV | Date | PROD | CHECK | APRV |
|---|---|---|---|---|---|
| All | 0 | 01/03/2012 | JDL | JDL | LTA |
| Conclusions updated | 1 | 01/23/2012 | JDL | JDL | LTA |
| | | | | | |
| | | | | | |

**AZTEC Engineering, Inc.**

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*January 30, 2012*

Mr. Alexander Sundquist
8MinuteEnergy
10100 Santa Monica Boulevard, Suite 300
Los Angeles, CA 90067

**Reflectivity Analysis**
**89ME Solar Facility**
**Calexico, California**

Dear Mr. Sundquist,

This reflectivity report is provided for evaluation of the 89ME photovoltaic solar facility with respect to the eventual impact that the project might cause to the crop dust airfield activity nearby the facility.

We appreciate the opportunity to provide our findings and professional opinions regarding reflectivity conditions at the site. If you have any questions or comments regarding our findings, please call our office at (602) 454-0402 or call me directly at (602) 458-7470.

Respectfully Submitted,

AZTEC Engineering, Inc.

Javier Damia
Solar Systems Design Manager

Distribution: Client (electronic copy)

# Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to the “Calexico Solar Farm II - 89MA” photovoltaic (PV) power plant being developed by 8MinutEnergy, LLC. Project location is surrounding one crop duster airfield in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the airfield runway if reflected sun light beam intersects the approaching flight path.

In addition, crop dusting flights can occur at nighttime. Because the airfield’s runway is not lit, aircrafts need to use an own spotlight when landing and taking-off. The reflection of the spotlights from PV modules is also analyzed to check for potential night-time reflection and bedazzle effect back to the airplanes.

Fig. 1 shows the location of the future PV plant relative to crop dust airfield:

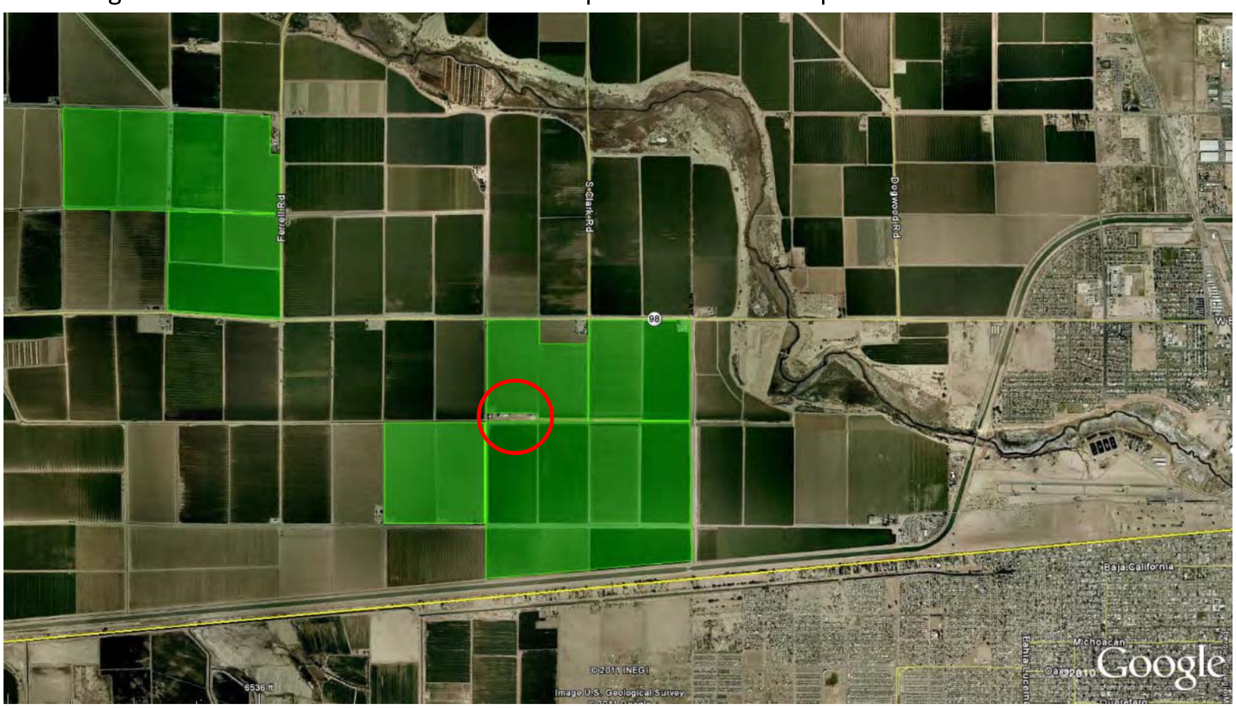


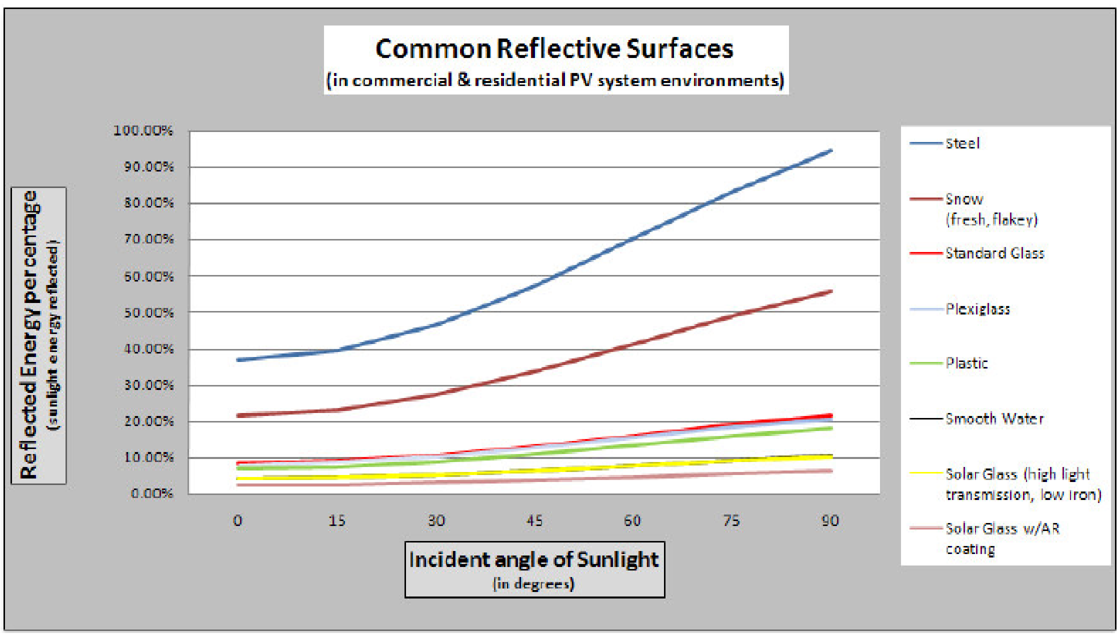

*Fig 1.- Location of PV Project and crop dust airfield*

To evaluate the risk of direct sun light and artificial light reflection a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer from direct reflection. Results from the mathematical analysis just help to evaluate intersection between the reflected beam and the airplane path; and as such, the possibility for a glint scenario to occur. Other relevant parameters, as intensity of the reflected beam or the subjective threshold for the intersection to produce bedazzle are beyond the scope of this report.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of this analysis:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun or artificial beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffuse light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and normally has negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules, for instance agricultural environment has higher Glare effect than PV modules. During night-time, the Glare effect due to artificial light (or moon light) is only noticeable in case of very high atmospheric turbidity, as happens in case of an intense fog.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to/from the airfield runway.

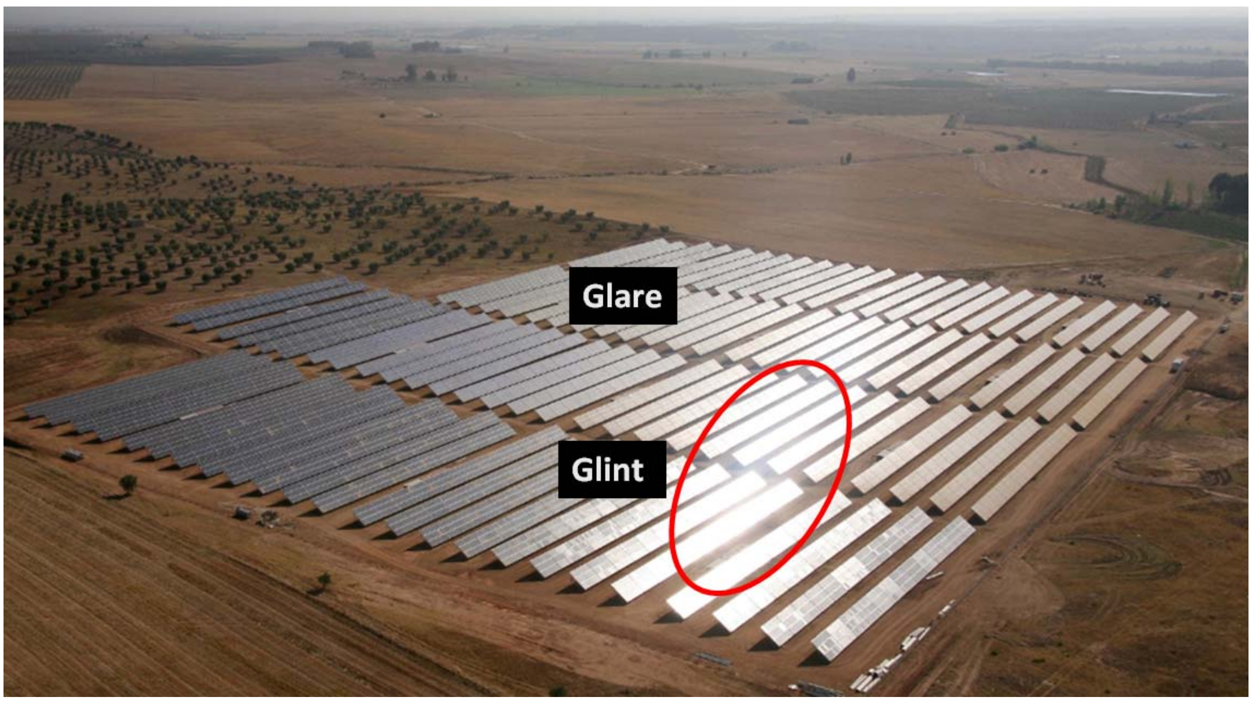



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Daytime analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the Northwest corner of the Plant, as shown in Fig. 3 below:

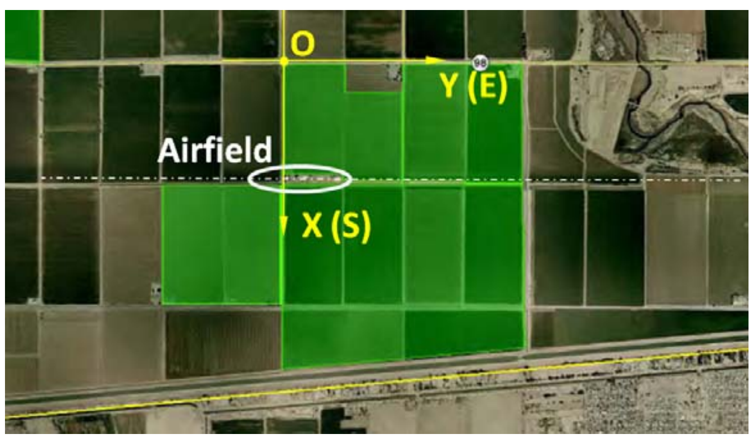



*Fig 3 .- Reference coordinate system*

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

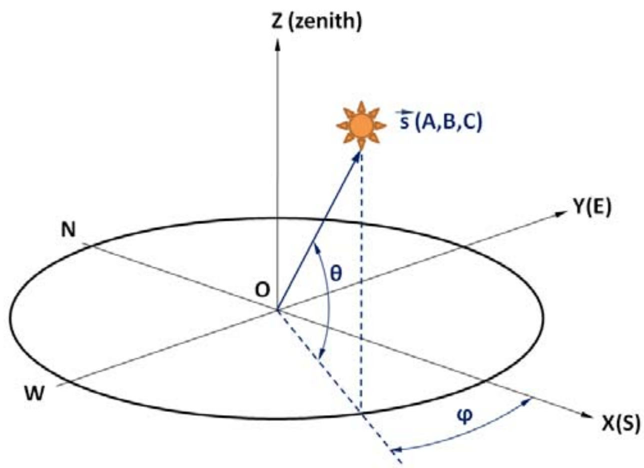



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta \ \cos\varphi$$
$$B = -\cos\theta \ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:
Earth declination:

$$D = 23.45 \ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D \ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32; … etc, until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc).

As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in the next graph:

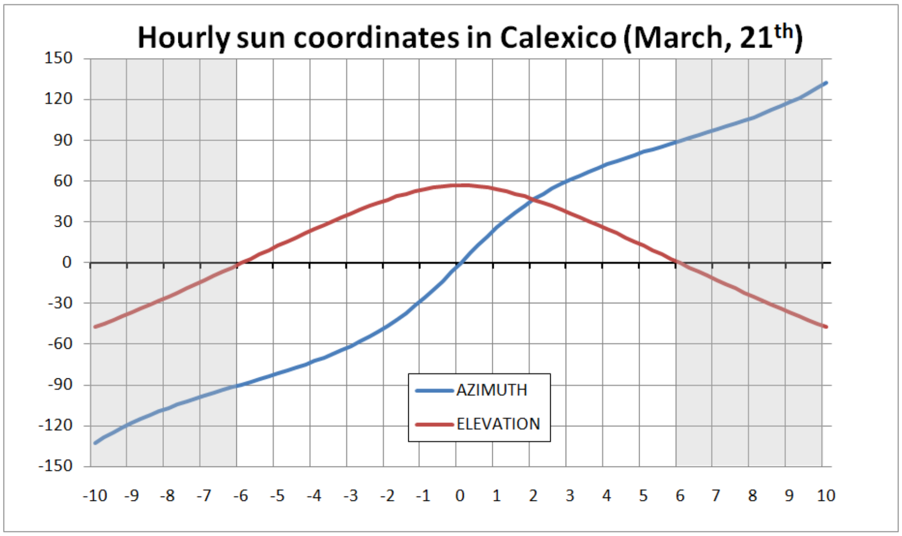



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

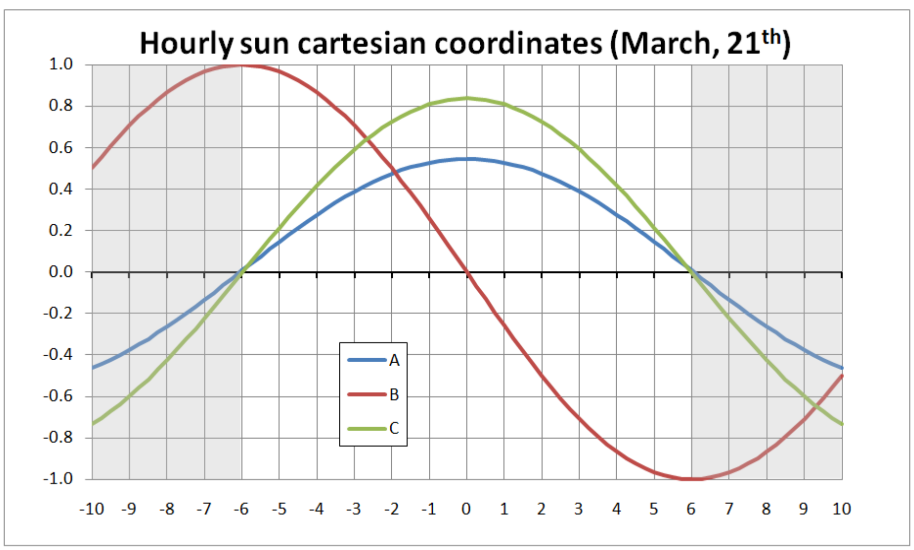



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located around the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

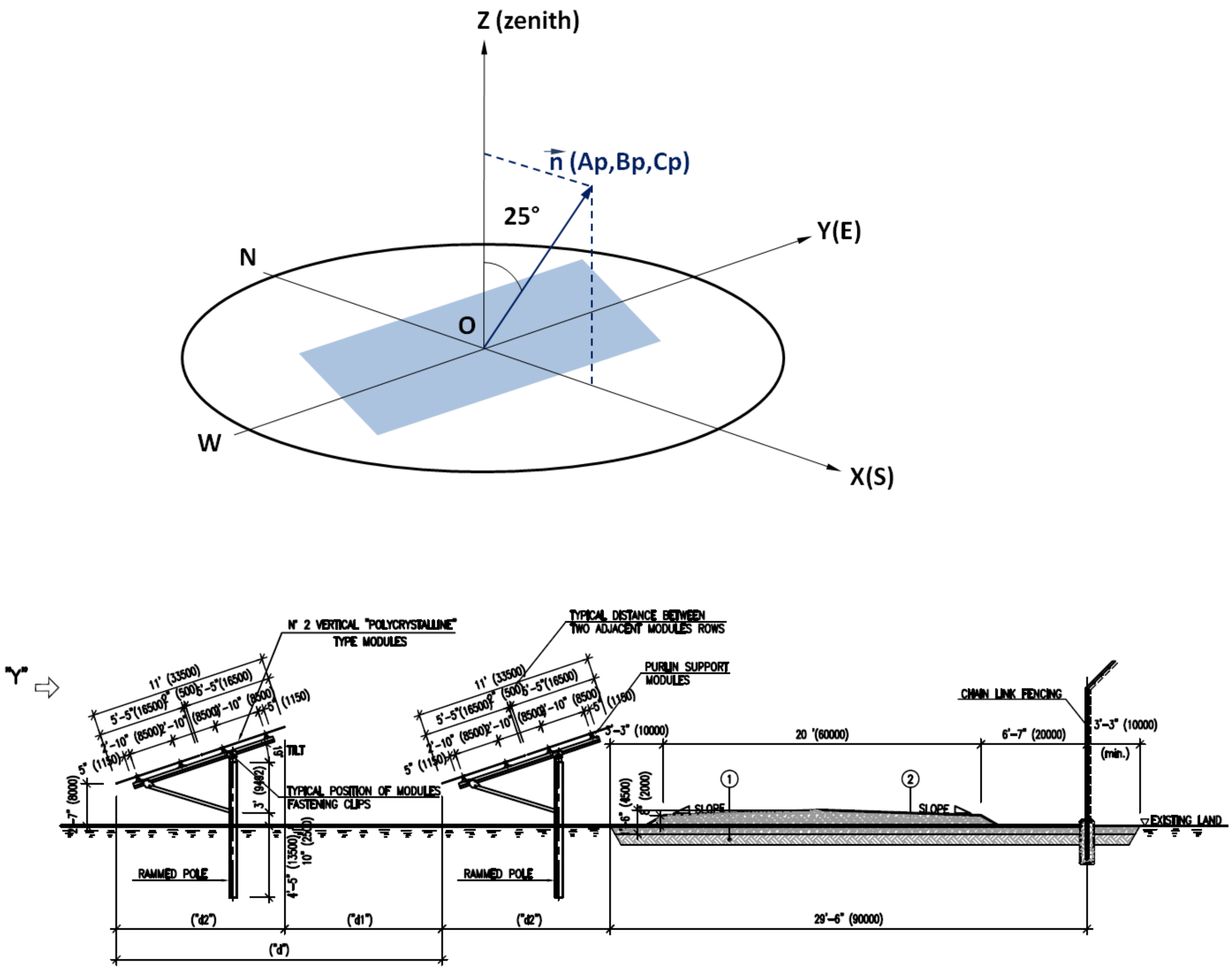
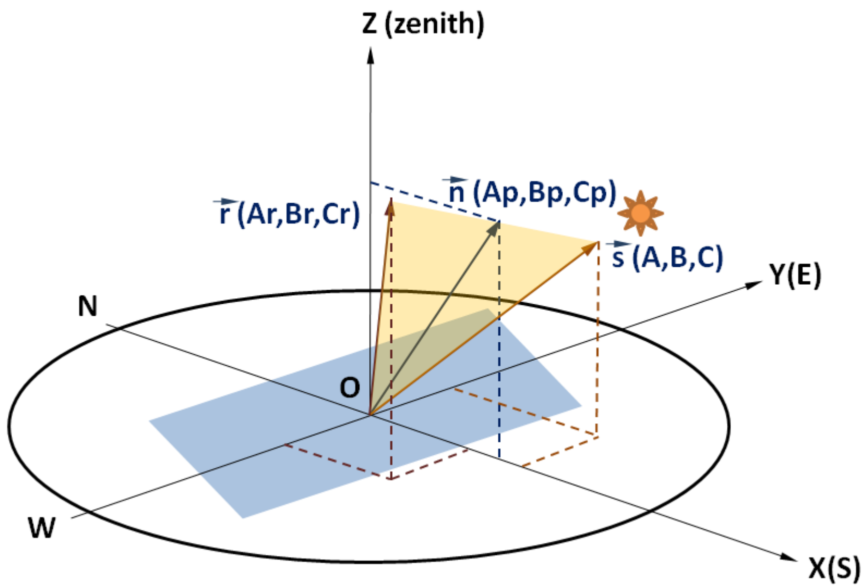



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:



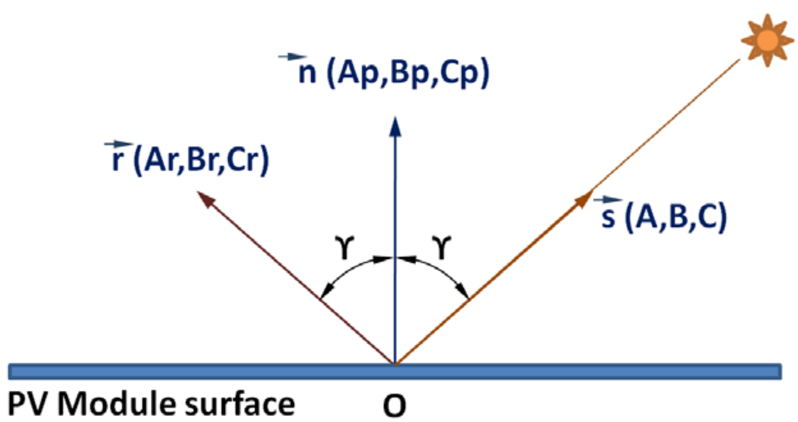




*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\,\vec{n} - \vec{s}$$

and its Cartesian coordinates are given by:

$$A_r = 2\ \cos\gamma\,A_p - A$$
$$B_r = 2\ \cos\gamma\,B_p - B$$
$$C_r = 2\ \cos\gamma\,C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

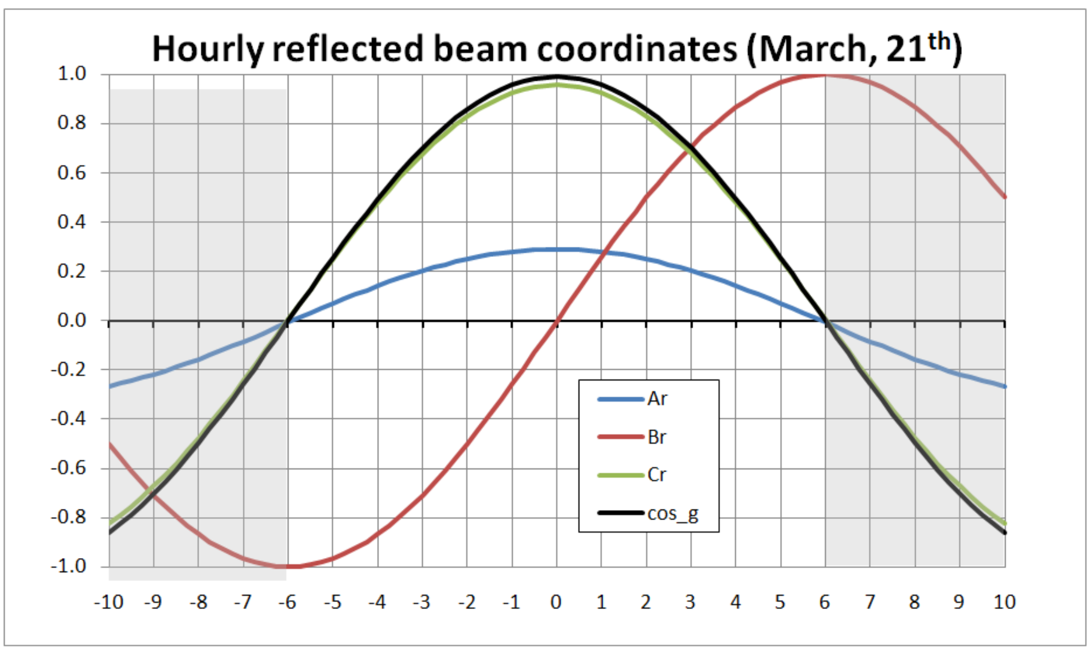



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity for fixed tilt PV systems at crop dust airfield

To define the location of relevant KVP it is hereby assumed that the approaching or departing airplane follows a straight line contained in a vertical plane (the "flight plane") that also contains the runway axis (Fig. 10).

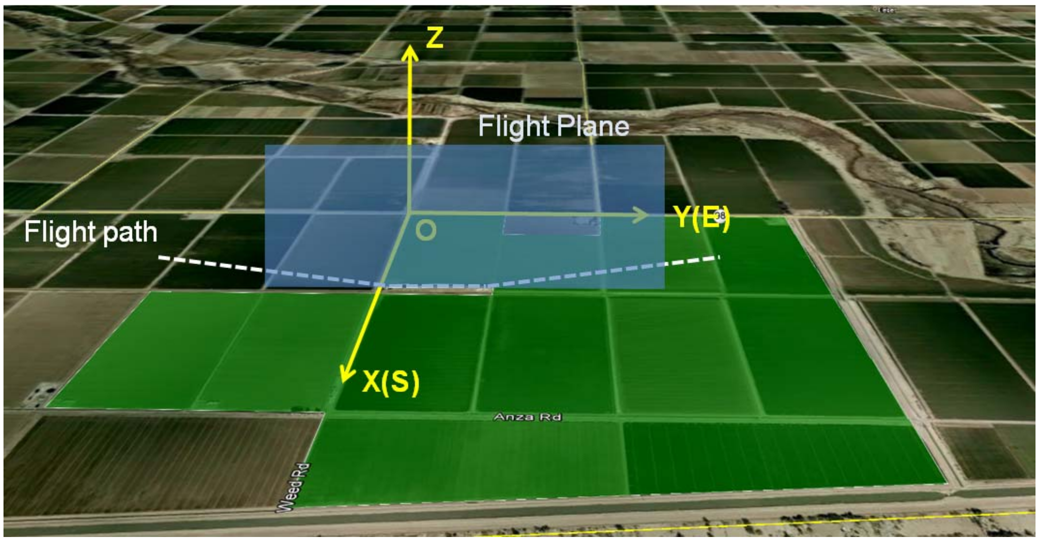



*Fig 10.- Geometry of approaching path*

The vertical flight plane containing the approaching path is defined by the following equation in the reference Cartesian axis system:

$$X \equiv 2{,}600 \text{ ft}$$

Several days along the year and at certain hours, a reflected beam vector will intersect the flight plane, but relevant glint might occur only if the intersection point belongs to the flightpath. The flight path is defined as the straight lines starting at both ends of the airfield runway with an angle between 3˚ and 6˚ from the horizontal. The Runway axis at ground level is also considered a part of the flight path.

A reflected solar beam will intersect the above flight plane at a given point $P_i$, with coordinates relative to the reference systems being $P_i = (x_i, y_i, z_i)$. As the sun moves along its daily path, the intersection point $P_i$ will define the corresponding trajectory curve in the flight plane. Whenever the curve drawn by successive $P_i$ intersects the flight path, at point $T_i$, there is a risk of glint. To calculate the position of the Pi points along the year, the following procedure applies:

Vector $OP_i$ is an extension of the reflected beam unit vector r = (Ar, Br, Cr), so vector Pi can be written as

$$\overrightarrow{OP_i} = t\,\vec{r}$$

where the proportionality factor [t] is given by the flight plane equation parameters as t = 2,600 / Ar

When calculating the intersection point coordinates (Pi), it is convenient to express them relative to a new coordinate system. The new coordinate system (X' , Y') contains the flight plane and the origin is located at the landing point, as shown in Fig. 10 above.

Position of point Pi referred to the new origin can be obtained with vector [L]:

$$\vec{L} = \overrightarrow{OP_i} - \overrightarrow{R_0}$$

Being vector [Ro] the position of the landing point in the original Cartesian coordinates:

$R_{o,x}$ = 2,600 ft $\quad$ $R_{o,y}$ = 0 $\quad$ $R_{o,z}$ = 0

Then

Lx = t Ar – 2,600 ft $\quad$ Ly = t Br $\quad$ Lz = t Cr

Finally, the coordinates of the intersection point in the flight plane reference axis $P_i$ = $(L_{x'} , L_{y'})$ are given by:

$$L_{x'} = \sqrt{L_x^2 + L_y^2} \qquad\qquad L_{y'} = L_z$$

Fig. 11 below shows the curve drawn by successive intersection points $P_i$ in the flight plane for some distributed sample days. Reflected beam source is the Northwest corner of the PV plant. The flight path and runway is also included.

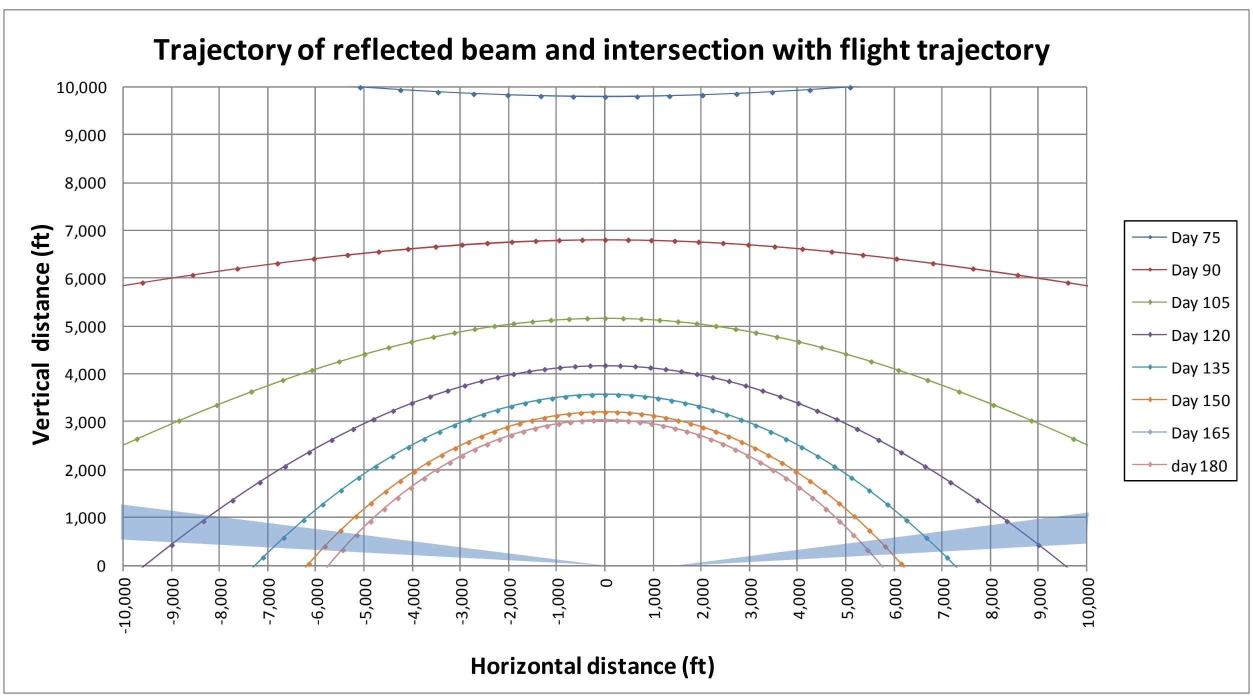



*Fig 11.- Intersection of reflected beam with flight path*

The flight path is assumed to be a straight line contained in the flight plane, with its origin at the runway end and at elevation angle between 3˚ and 6˚.

Other corners of the PV plant perimeter shall produce similar curves, so the reflection pattern for the plant section North of the airfield is a parallelogram built by joining the respective reflection paths from its corners. Fig. 12 shows the reflection parallelogram for day 180 at 3:00 pm, with the superimposed most probable flight trajectory envelope around the airfield.

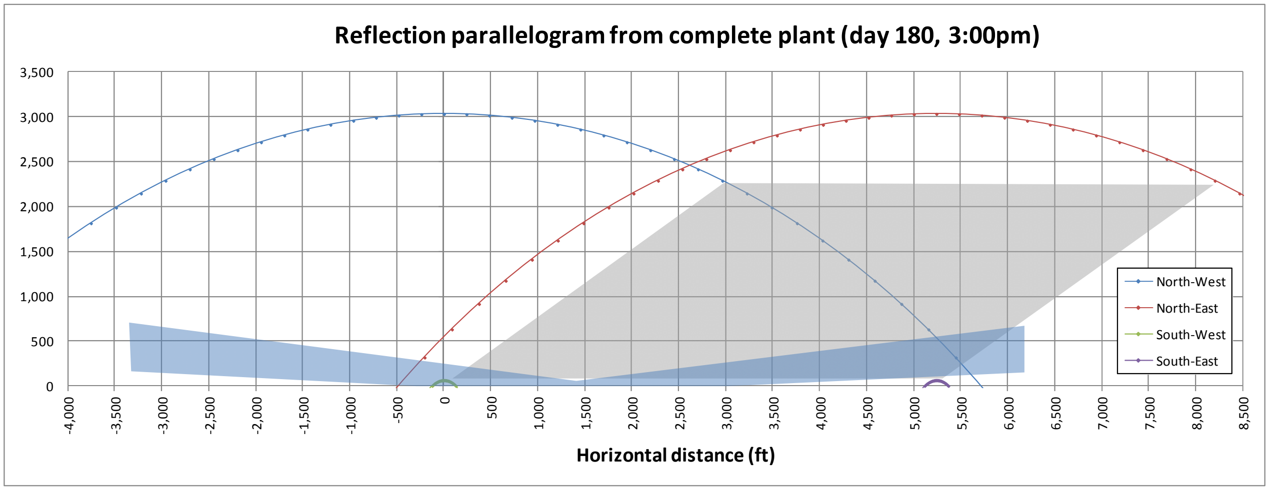



*Fig. 12 – Reflection pattern for the complete plant*

Clearly, there is a long-term intersection between the direct glint and the flight trajectory when approaching the airfield from East at afternoon hours (or symmetrically approaching from West at morning hours).

The same conclusions can be obtained for most of the year. This is because the plant is very close to the airfield, thus sun reflections are almost permanently intersecting with the flight path.

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.

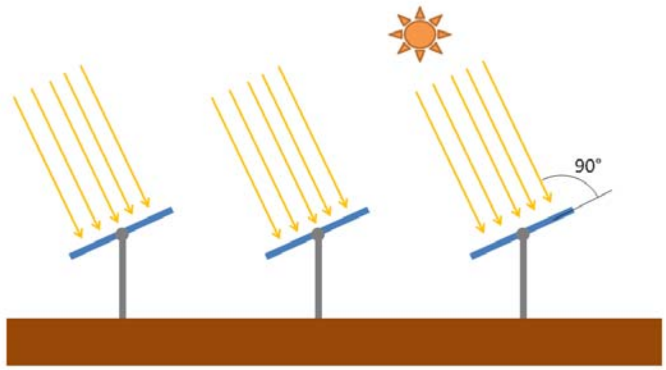



*Fig 13.- Tracking angle of horizontal axis trackers*

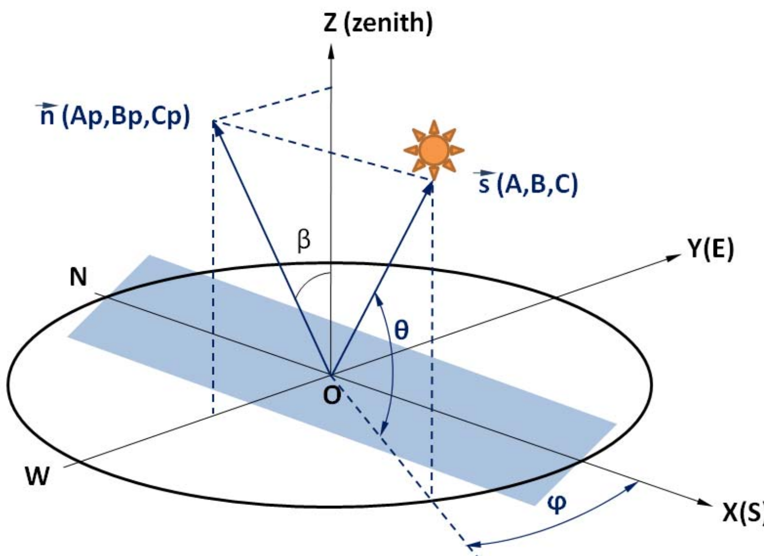



*Fig 14.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

this can be written as

$$\cos\gamma = -B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\,(\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad\qquad \tan\beta = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers could be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

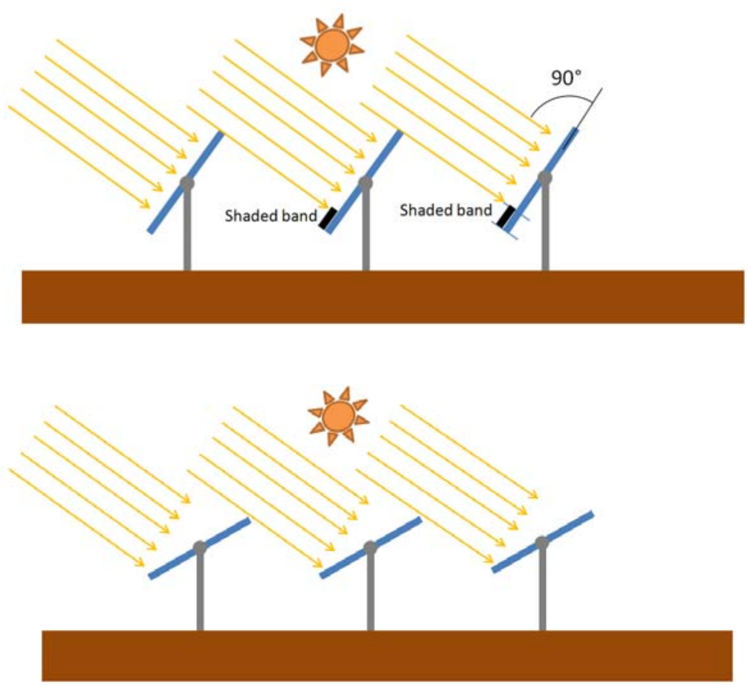



*Fig 15.- Above: Mutual shading without backtracking.*
*Below: Backtracking corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons. Fig. 17 shows the tracker angle, together with sun elevation angle for a sample day (March, 21[st]).

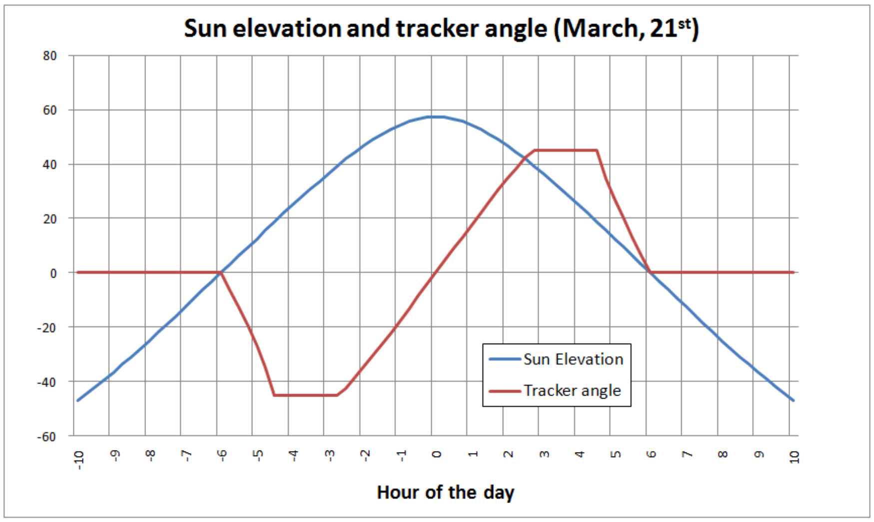



*Fig 16.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 18,

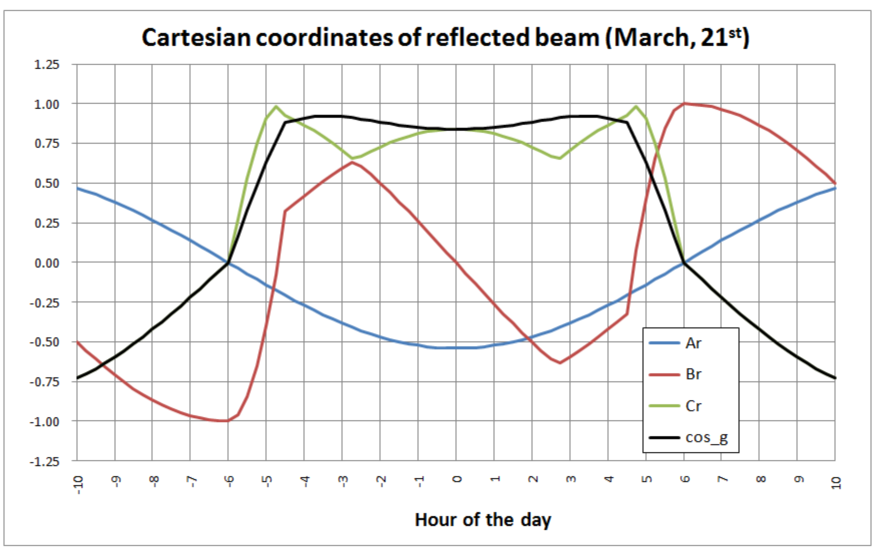



*Fig 17.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at crop dust airfield

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The vertical flight plane is parallel to the East-West direction, as shown in Fig.10. Several days along the year and at certain hours, a reflected beam vector will intersect with the flight plane, but relevant glint might occur only if the intersection point is within the flight path.

To analyze the risk of glint, the trajectory of the intersection point is evaluated for various days. The trajectory is compared with the flight path and glint risk evaluated for precise time. Calculated results are shown in Fig. 18, for beams reflected by the Southwest corner of the plant.

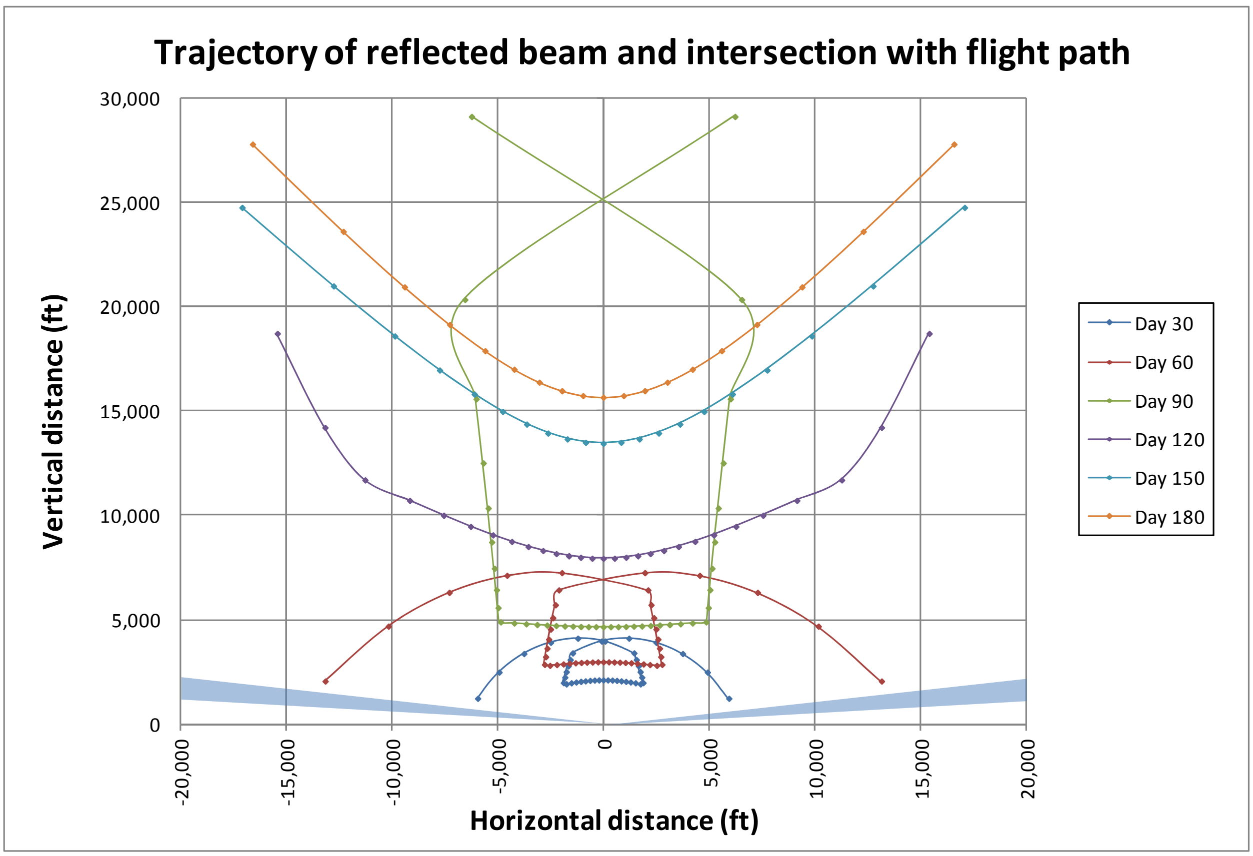



*Fig 18.- Trajectory of reflected beam intersection with flight plane along the year.*

Other corners of the PV plant perimeter shall produce similar curves, so the reflection pattern for the plant section South of the airfield is a parallelogram built by joining the respective reflection paths from its corners. Fig. 19 shows the reflection parallelogram for day 60 at 3:00 pm, with the superimposed most probable flight trajectory envelope around the airfield.

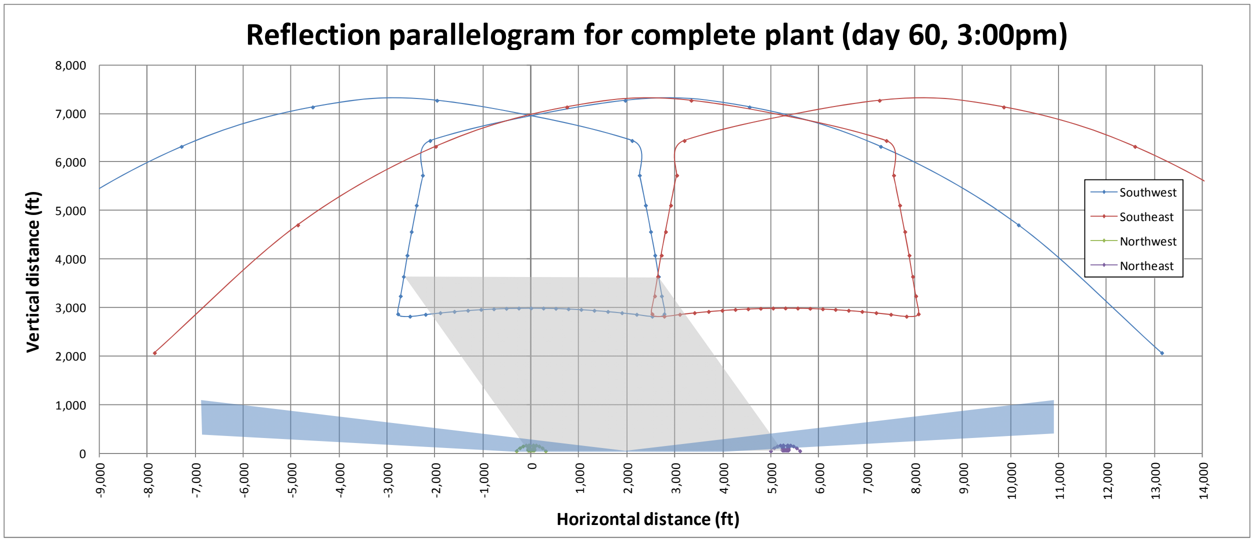



*Fig. 19 – Reflection pattern for the complete plant*

As it occurred with the fixed tilt case, there is risk for long-term glint due to the proximity of the PV modules to the South boundary of the airfield runway. Similar results would be obtained for any other days along the year.

## 3.7 Reflection equations for tilted axis trackers

Tilted axis trackers are oriented in North-South direction, so the modules attached to the tilted rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates, similarly to horizontal axis trackers. In this case, the inclined axis provides a lower incidence angle to the PV module's plane. Fig. 20 shows a typical tilted axis tracker:

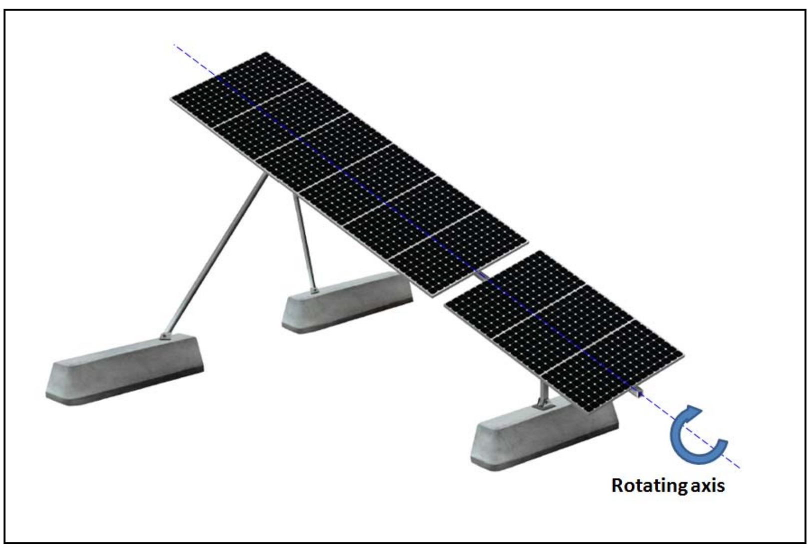



*Fig 20.- Typical tilted axis tracker*

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the tilted tracker axis. Target is to keep the incidence angle as close a zero as possible.

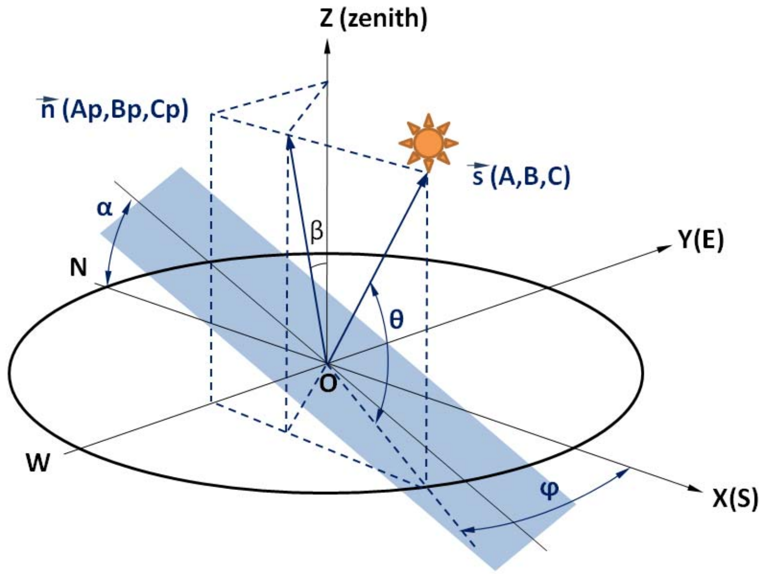



*Fig 21.- Normal vector to PV modules in an tilted axis tracker*

Given the fixed tilt angle of the tracker being (α) and instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = cos\beta \sin\alpha$$
$$B_p = -\sin\beta$$
$$C_p = cos\beta \cos\alpha$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + C\,C_p$$

this can be written as

$$\cos\gamma = -\,B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d(\cos\gamma)}{d\beta} = -A\sin\beta\sin\alpha - B\cos\beta - C\sin\beta\cos\alpha = 0$$

$$\tan\beta = -\frac{B}{A\sin\alpha + C\cos\alpha}$$

which describes the rotation angle of the tracker in function of sun position, and thence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.7.1 Backtracking

Similarly to the horizontal axis tracker case, at low sun elevation angles (i.e., sunrise and sunset), the trackers could be fully deployed and mutual shading between modules belonging to the same alignment of trackers would occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

Fig. 22 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

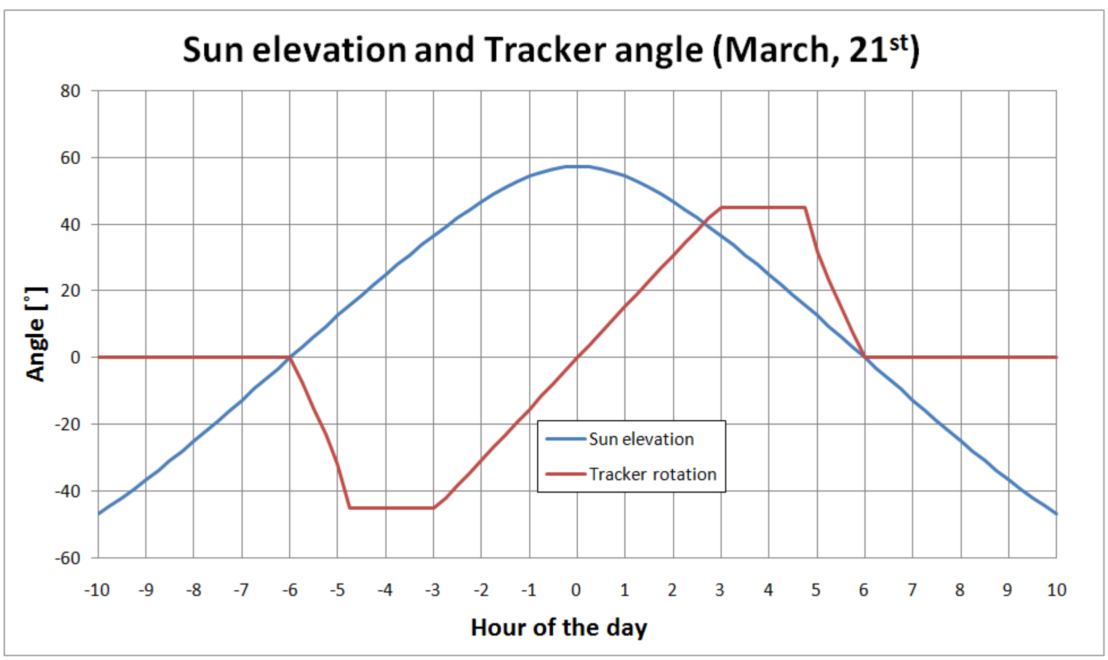



*Fig 22.- Tracker angle on a sample day for tilted axis tracker (α=20°)*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 23,

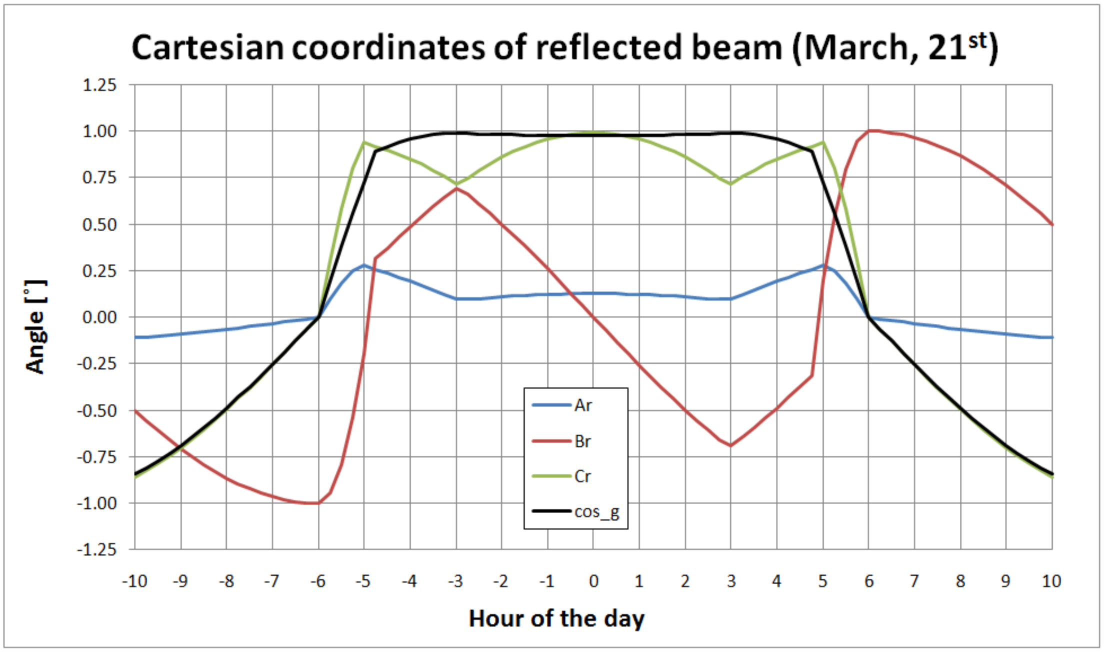



*Fig 23.- Cartesian coordinates for reflected beam on a sample day.*
*It can be seen that incidence angle is lower than with horizontal axis trackers (Fig. 17)*

## 3.8 Reflectivity analysis with tilted axis trackers at crop dust airfield

The procedure described in 3.4 is repeated now for the moving reflecting surfaces on a tilted axis tracker. The vertical flight plane is parallel to the East-West direction, as shown in Fig.10. Several days along the year and at certain hours, a reflected beam vector will intersect with the flight plane, but relevant glint might occur only if the intersection point is within the flight approaching path, in either East or West directions.

To analyze the risk of glint, the trajectory of the intersection point is evaluated for several days along the year. The trajectory is compared with the flight path and glint risk evaluated for precise time. Calculated results are shown in Fig. 24. The glint source is the Northwest corner of the PV plant.

Other corners of the PV plant perimeter shall produce similar curves, so the reflection pattern for the plant section North of the airfield is a parallelogram built by joining the respective reflection paths from its corners. Fig. 25 shows the reflection parallelogram for day 135 at 3:00 pm, with the superimposed most probable flight trajectory envelope around the airfield.

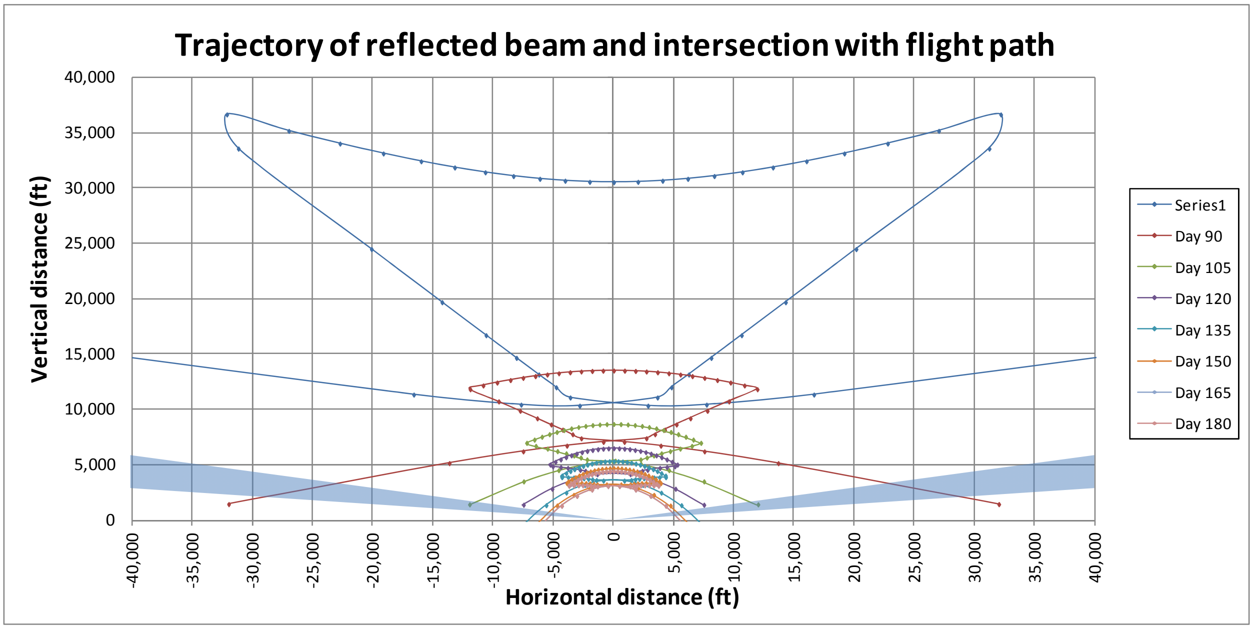



*Fig 24.- Trajectory of reflected beam intersection with flight plane along the year.*

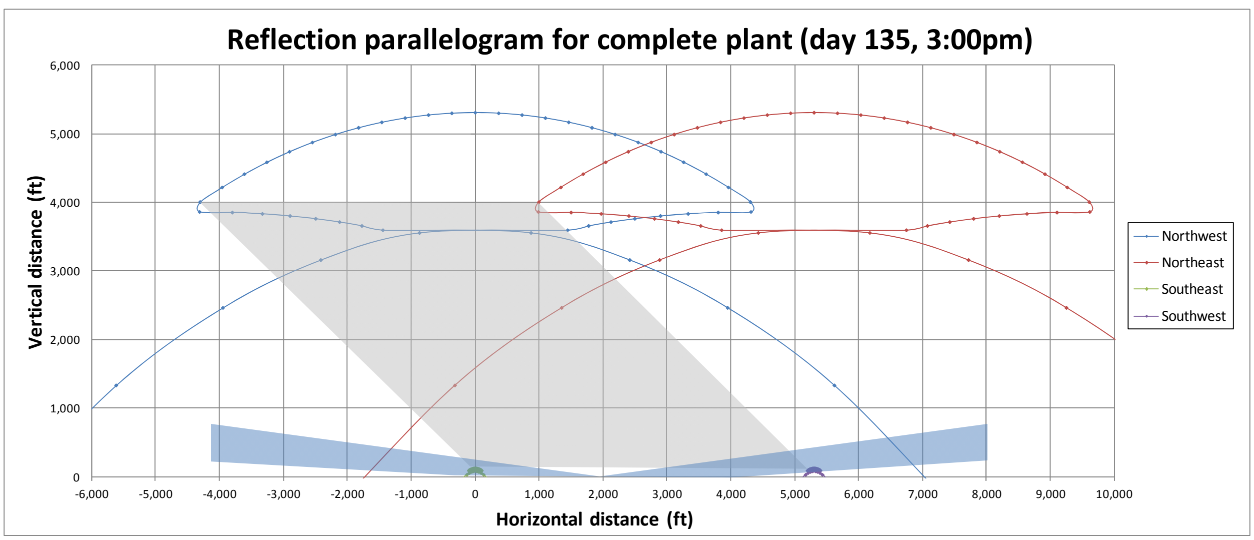


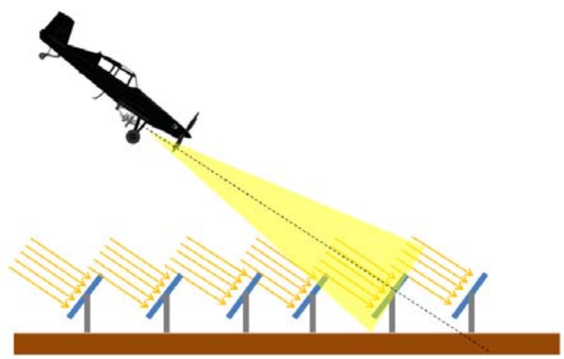

*Fig. 25 – Reflection pattern for the complete plant*

As it occurred with the fixed tilt case, there is risk for long-term glint due to the proximity of the PV modules to the North boundary of the airfield runway. Similar results would be obtained for any other days along the year.

# 4 Nighttime analysis

Crop dust airplanes might operate at nighttime. Because the airfield is not lit, airplanes are equipped with headlights for take-off and landing maneuvers. Airplanes land and take off at angles between 3° and 6°.

Since the airfield runway is oriented East-West, glint could only occur with PV modules facing perpendicularly the airplane path. This possibility could arise only for horizontal axis trackers at maximum deployment angle (± 45°) and only if the airplane is landing with an angle of 45°. As noted above, airplanes land and take off at angles between 3° and 6°, therefore airplanes landing at 45° is far from normal operation.



Any other arbitrary flight path over the PV plant would seldom produce direct glint at nights, since the required perpendicularity condition would require the airplane to approach the PV field with an angle of 65° in North-South direction for the fixed tilt PV modules, or similar exaggerated angles for the one axis tilted case. It can be concluded that direct glint during night flights will never occur in normal circumstances.

The effect of glare from a strong headlight is difficult to predict when the airplane is very close to the PV modules, which is the case just before landing. Because glare is not directional and depending on atmospheric conditions, evaluation shall be done by means of 3D graphic simulations (section 4.1 below).

## 4.1 3D graphic simulations for night flight conditions

The following images show the result of a 3D graphic simulation for night flight conditions including the PV plant and the approaching airplane with normal landing angles. This is the scenario used to evaluate the effect of glare caused by airplane headlights for the worst case (single horizontal axis tracker at 45° facing the airplane).

It can be seen that self-glare due to headlights has a negligible effect in visibility for maneuvering. Conclusion is that the PV plant will not affect visibility at nighttime flight conditions.

*Image 1 – PV plant around the airfield with plane landing from West (daytime)*

*Image 2 – View from cockpit when landing (daytime)*

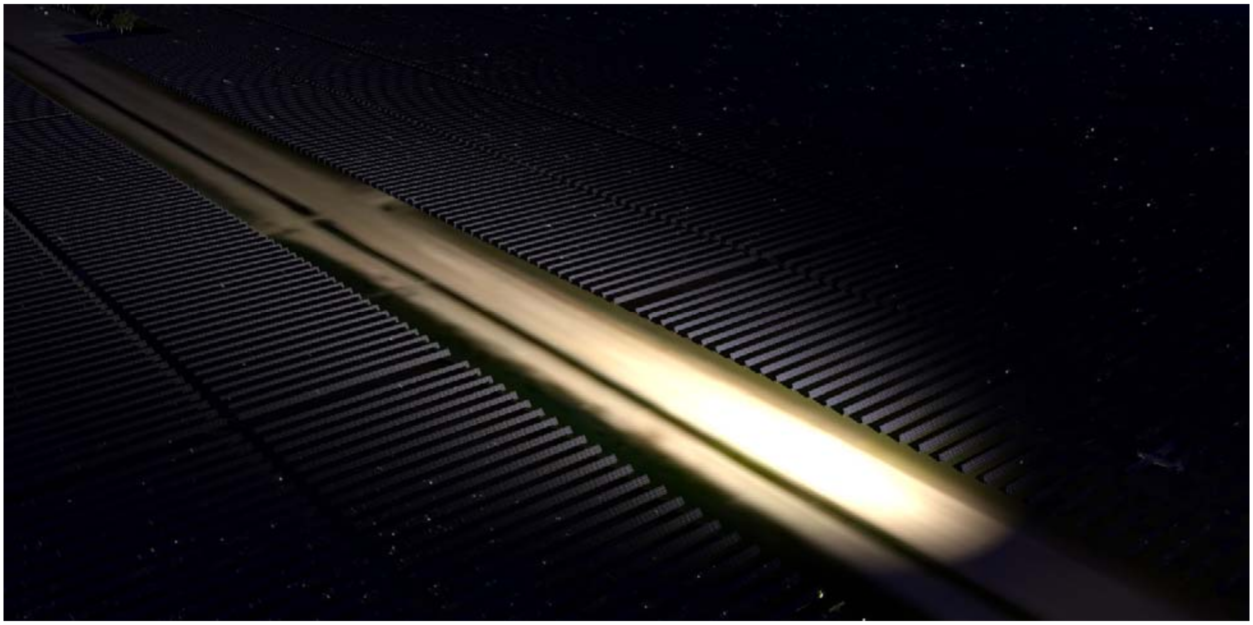


*Image 3 – General view when landing (nighttime with headlights)*

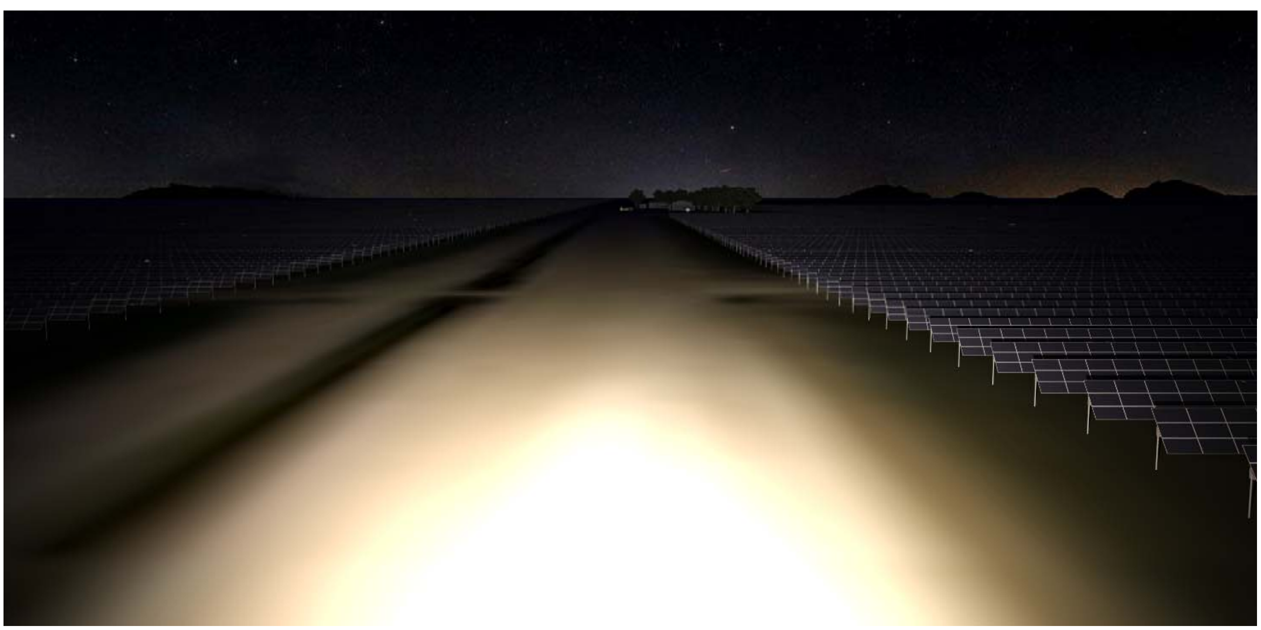


*Image 4 – View from cockpit when landing (nighttime with headlights)*

# 5 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected as visible light. Although this can still produce some glint to KVPs, in this case airplanes landing at or taking-off from an existing crop dust airfield, it should be noted that other sources of directional glint or glare are always present in the landscape around airfields. These sources include lakes, snow, steel roofs in industrial areas, glass from vertical buildings, and even wet crop. In all of these examples, reflectivity characteristics of such materials are higher than PV modules (e.g., 10% for water, 80% for steel, 20% for glass).

To determine the risk of glint, a geometric analysis is done for several scenarios: Fixed tilt PV modules, Horizontal Axis trackers and Tilted Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes. All mathematical expressions hereby described are implemented in a computer routine. Results from the mathematical analysis just help to evaluate eventual geometric overlap between the reflected beam and the airplane path (i.e., the possibility for a glint scenario to occur).

According to the mathematical analysis, geometric conditions for glint scenarios could occur from PV modules installed in plant section North of the runway (for fixed tilt and inclined axis trackers), and from modules installed in plant section South of the runway (for horizontal axis trackers). In some cases, when the reflected beam could be nearly parallel to the runway axis, the pilot would be directly facing the sun's disk simultaneously, which is much brighter than the reflection itself. Geometric glint may happen also during central hours, with high sun elevation angles and the sun disk not directly in pilot's visual path. In those cases, reflected light could be directed at the airplane perpendicularly to its path; i.e., the pilot would have to turn his head to the side and look away from the runway axis to be affected by this direct glint reflection.

Based on our analysis, self glint or glare from airplanes' headlights during landing or taking-off to the airfield at nights will never occur under normal maneuvering conditions.

# APPENDIX G

## Glare Analysis for Air Traffic

# MOUNT SIGNAL Solar Farm (82LV 8ME, LCC)

# REFLECTIVITY ANALYSIS

REVISION INDEX

| Page/Reason | REV | Date | PROD | CHECK | APRV |
|---|---|---|---|---|---|
| All | 0 | 04/13/2010 | JDL | JDL | JDL |
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# Contents

# 1 Introduction

This document analyzes the risk of sun reflectivity due to a series of photovoltaic (PV) power plants being developed by 82LV 8ME, LLC. Project location is nearby the Calexico airport in Imperial County, CA. Reflectivity events due to the presence of PV modules might affect airplane visibility while approaching the corresponding airport runway if reflected sun light beam intersects the approaching flight path.

Fig. 1 shows the location of the future PV plant relative to Calexico airport.

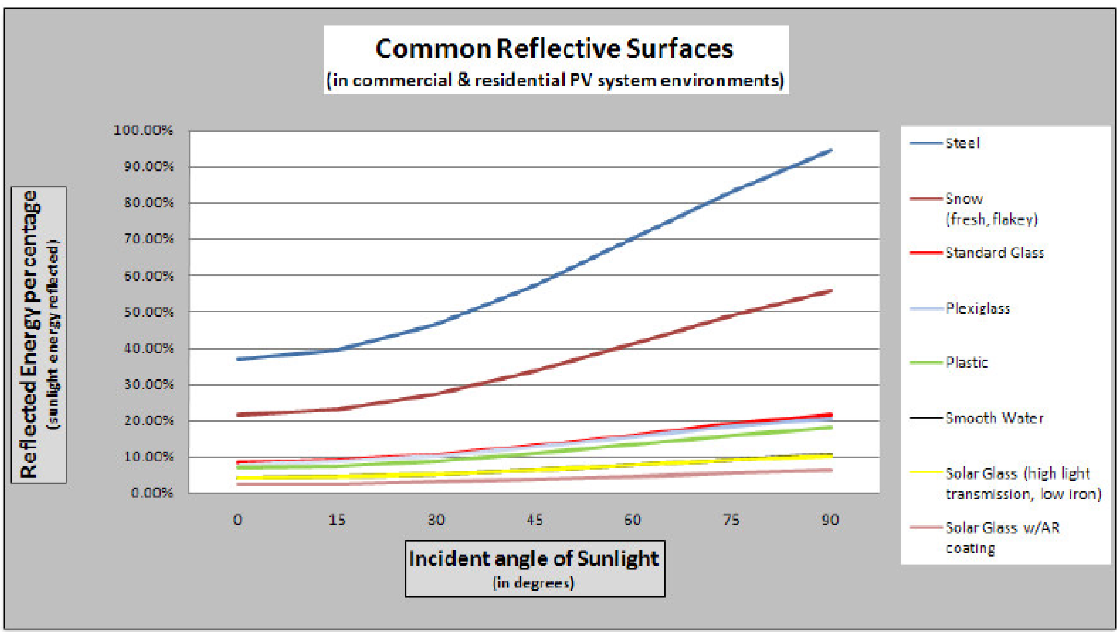

*Fig 1.- Location of PV Project and Calexico airport*

To evaluate the risk of direct sun light reflection events a mathematical (geometric) model has been developed. The model predicts when in the year there is a possibility for approaching or taking-off airplanes to suffer direct reflection.

# 2 Definitions

The following definitions and descriptions are key to understanding the methodology and results of the study:

**Photovoltaic Module** – Photovoltaic panels, also known as PV modules. By nature, PV panels are designed to absorb as much of the solar spectrum as possible in order to convert sunlight to electricity. Reflectivity levels of solar panels are decisively lower than standard glass or galvanized steel, and should not pose a reflectance hazard to viewers. The next graph relates the reflectivity properties of solar modules in function of the incidence angle, and compares with other common reflecting surfaces in an airport environment:




Reflected light from PV modules' surface is just between 10% - 20% of the incident radiation, as low as water surfaces, while galvanized steel (used in industrial roofs) is between 40% and 90%. It should also be noted that high incidence angles are always related to low sun elevation angles (i.e, the sun beams are close to be tangent to the reflecting surface) and, in this case, the intensity of incident light is much lower than -say- noon time.

**Glint** – Also known as a specular reflection, produced by direct reflection of the sun beam in the surface of the PV solar panel. This is the potential source of the visual issues regarding viewer distraction. Glint is highly directional, since its origin is purely reflective.

**Glare** – Is a continuous source of brightness, relative to diffused light. This is not a direct reflection of the sun, but rather a reflection of the bright sky around the sun disk. Technically this is described as the

reflection of the circumsolar diffuse component. Glare is significantly less intense than glint and have negligible effects. As Glare is the reflection of diffuse irradiance is not directional. Other glare sources in the nature (often called Albedo reflectance) are much more intense that glare from PV modules, for instance even agricultural environment has higher Glare effect than PV modules.

**Key View Point (KVP)** – KVPs are viewpoints used in the glint and glare study. In this analysis, KVP can be any point in the most probable airplane approaching path to the airport runway.

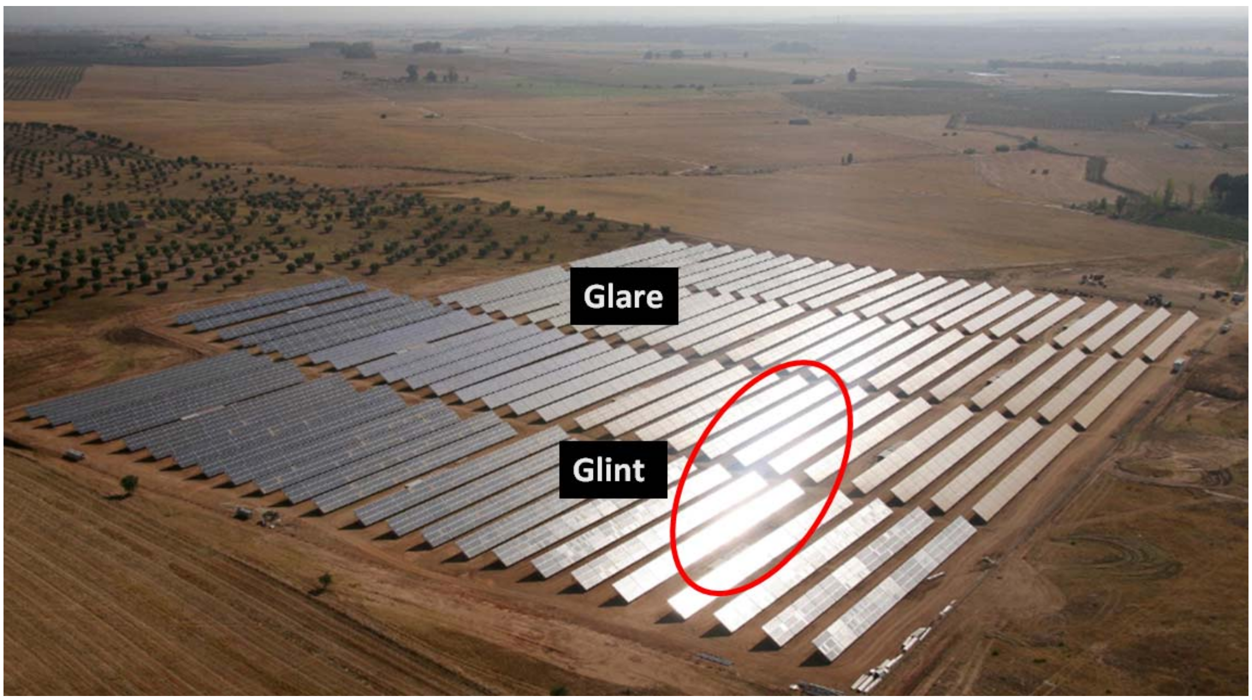



*Fig 2 .- Glint and Glare identification from a PV installation*

# 3 Mathematical analysis

## 3.1 Reference coordinate system

Solar reflection from flat surfaces is a mathematical problem that can be solved by means of 3D geometry concepts. In order to properly relate sun position, PV modules position and orientation, and KVP location; is necessary to define a global coordinate system to which the previous position and orientation will be referred to.

In this analysis, the 3D Cartesian coordinate system is defined as follows:

| | |
|---|---|
| Positive X-Axis | Pointing South |
| Positive Y-Axis | Pointing East |
| Positive Z-Axis | Pointing upwards |

Origin of the coordinate system is chosen at the future PV plant location, as shown in Fig. 3 below:

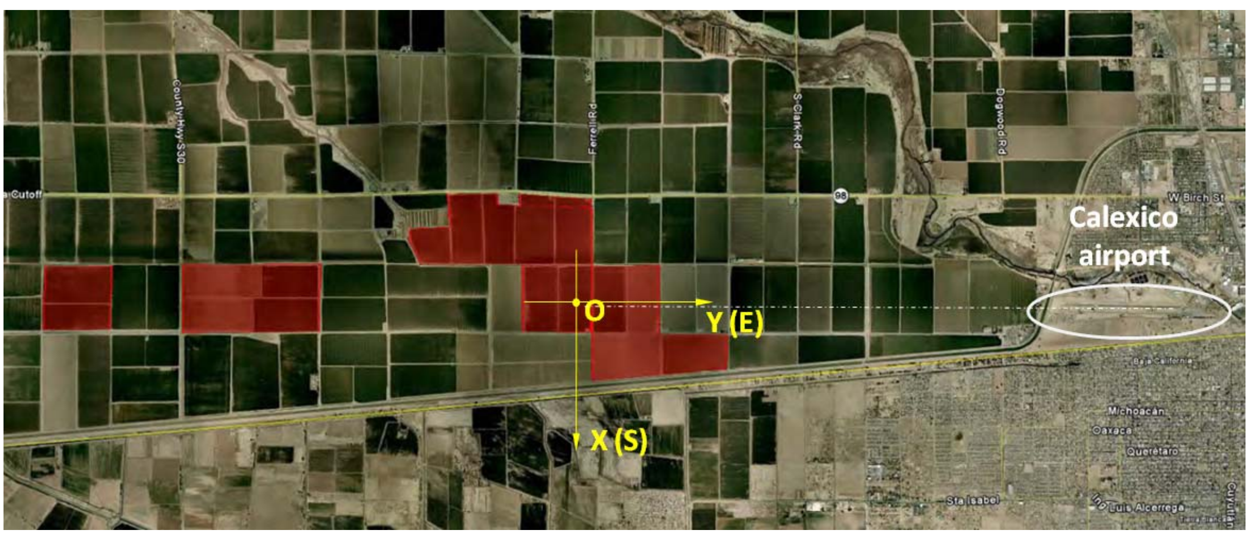



*Fig 3 .- Reference coordinate system*

## 3.2 Sun position

Instantaneous sun position is defined by two angular (spherical) coordinates. These angles are Azimuth (φ) and Elevation (θ). Azimuth is the deviation of sun's horizontal projection from South, while elevation is the angle between the horizontal plane and sun's position. The following graphs illustrates above definitions, and criteria for positive values:

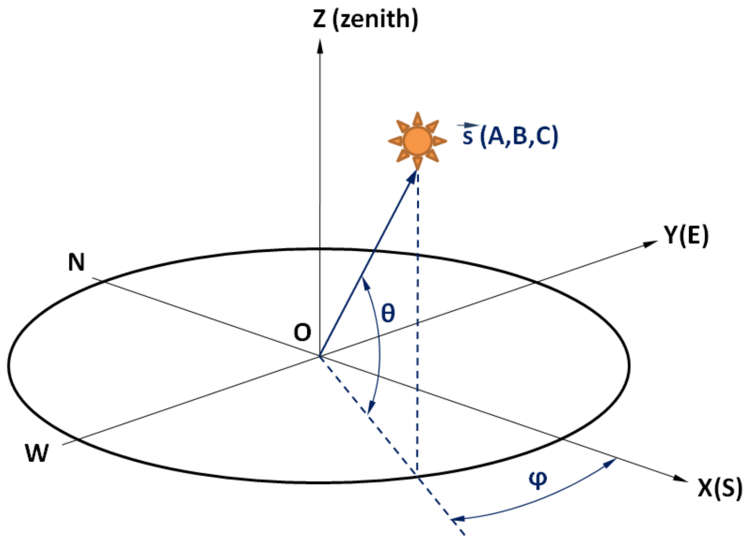



*Fig 4.- Sun position coordinates*

Sun position can be also defined by a unit-length pointing vector s = (A, B, C). Cartesian coordinates of the sun position vector are written in terms of the azimuth and elevation angles as follows:

$$A = \cos\theta\ \cos\varphi$$
$$B = -\cos\theta\ \sin\varphi$$
$$C = \sin\theta$$

Azimuth and elevation angular coordinates (φ, θ) are both function of:

- Earth latitude (L) at the origin
- Time: Day of the year (i) and hour of the day (H)

and can be calculated as per the following equations:

Earth declination:

$$D = 23.45\ \sin(0.986[284 + i])$$

Azimuth and elevation angles:

$$\sin\theta = \sin D \sin L + \cos D \cos L \cos H$$
$$\cos\varphi = \frac{\sin D\ \cos L - \cos D \sin L \cos H}{\cos\theta}$$

In the above expressions the day of the year (i) is following a Julian day convention (January, 1st is i=1; February, 1st is i = 32,… until i =365). The hour of the day (H) is referred to noon time (12:00 is H = 0; 10:00 is H = -2; 14:00 is H = +2; … etc).

As an example, the calculated values for azimuth and elevation angles for the equinox (March, 21st, i = 80) are plotted in function of the hour of the day in the next graph:

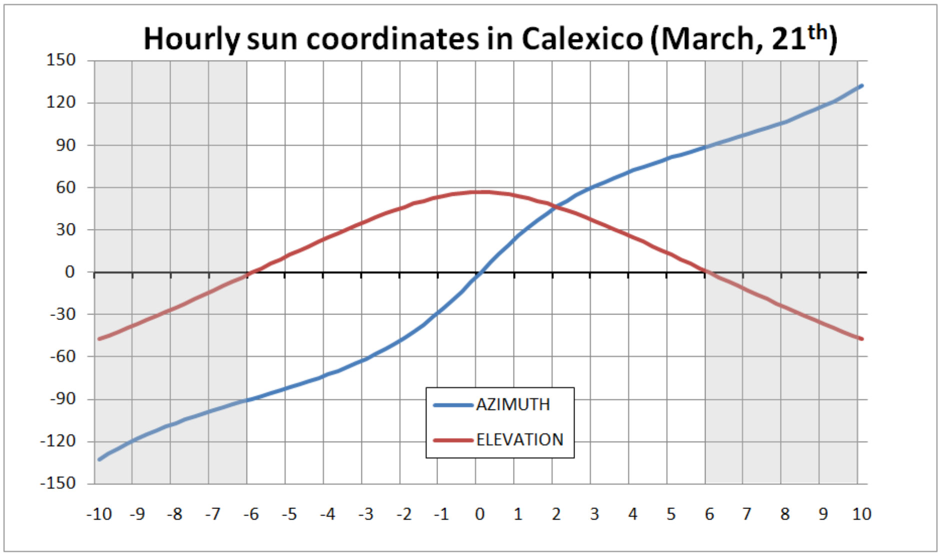



*Fig 5.- Sun position coordinates in function of hour of the day*

Negative values of the elevation angle means night time (the sun is below the horizon). In the above example the daylight period is 12 hours and the azimuth at sunrise is -90° (pure East), as expected for the equinox. Maximum elevation angle (at noon) is 56.88° for this latitude and particular day.

For the purpose of geometric calculations later in this report, the relevant results are the Cartesian coordinates of the sun position vector (A, B, C). For the sample day above, these are plotted in Fig. 6:

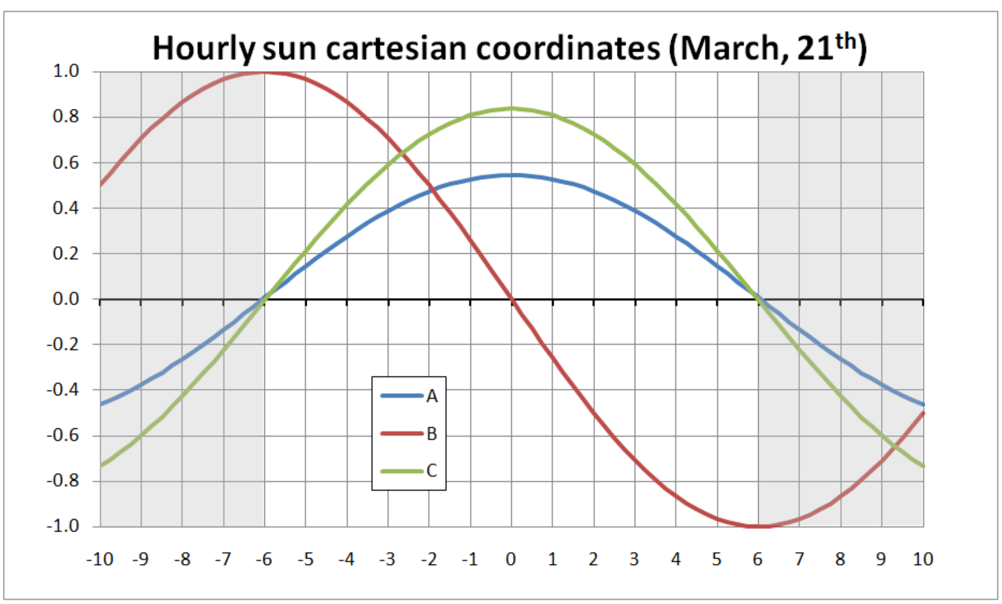



*Fig 6.- Sun position Cartesian coordinates in function of hour of the day*

## 3.3 Reflection equations for fixed tilt system

PV modules are considered reflecting planes located at the origin of the coordinate system (O). A plane is geometrically defined by its perpendicular (normal) unit vector [n].

Notation for Cartesian coordinates of this fixed vector is n = (Ap, Bp, Cp). From the PV plant optimum design, the PV modules are facing South with a tilt angle of 25°, as shown in Fig. 7.

Then the fixed coordinates of this normal vector for the reflecting plane are given by:

$$A_p = \sin 25° = 0.42262$$
$$B_p = 0$$
$$C_p = \cos 25° = 0.90630$$

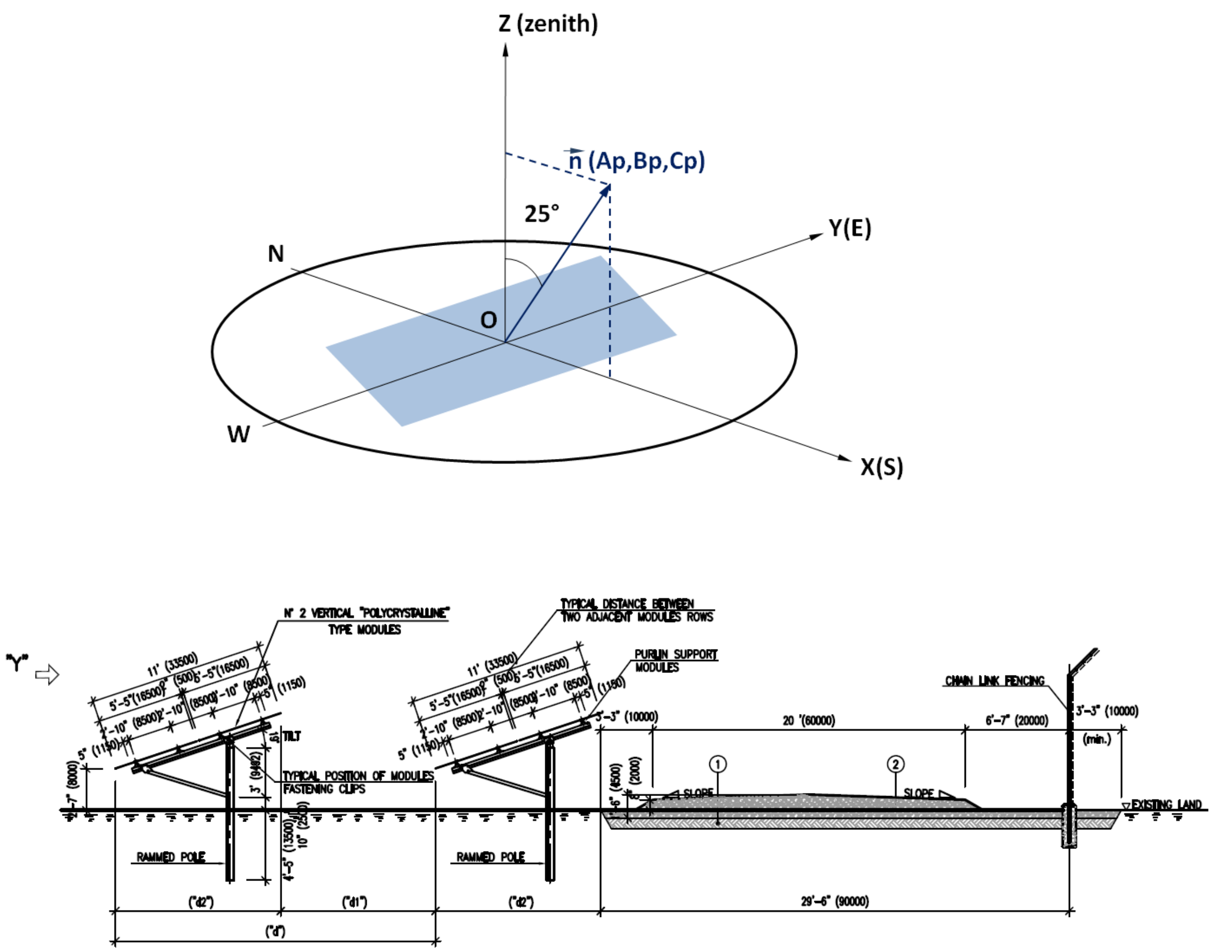



*Fig 7.- Reflecting surfaces – Coordinates and typical PV design*

Reflection of sun beams by a given surface can be calculated once the direction of the incident beam and plane orientation is known.

Instantaneous solar beam direction vector s = (A, B, C) and reflecting plane normal vector n = (Ap, Bp, Cp) intersects at the origin, and both defines a new plane in the space. From reflectivity laws, the reflected beam vector r = (Ar, Br, Cr) will be contained in this plane and symmetric to the incident beam with respect to the reflecting surface vector, as shown in the next figures:

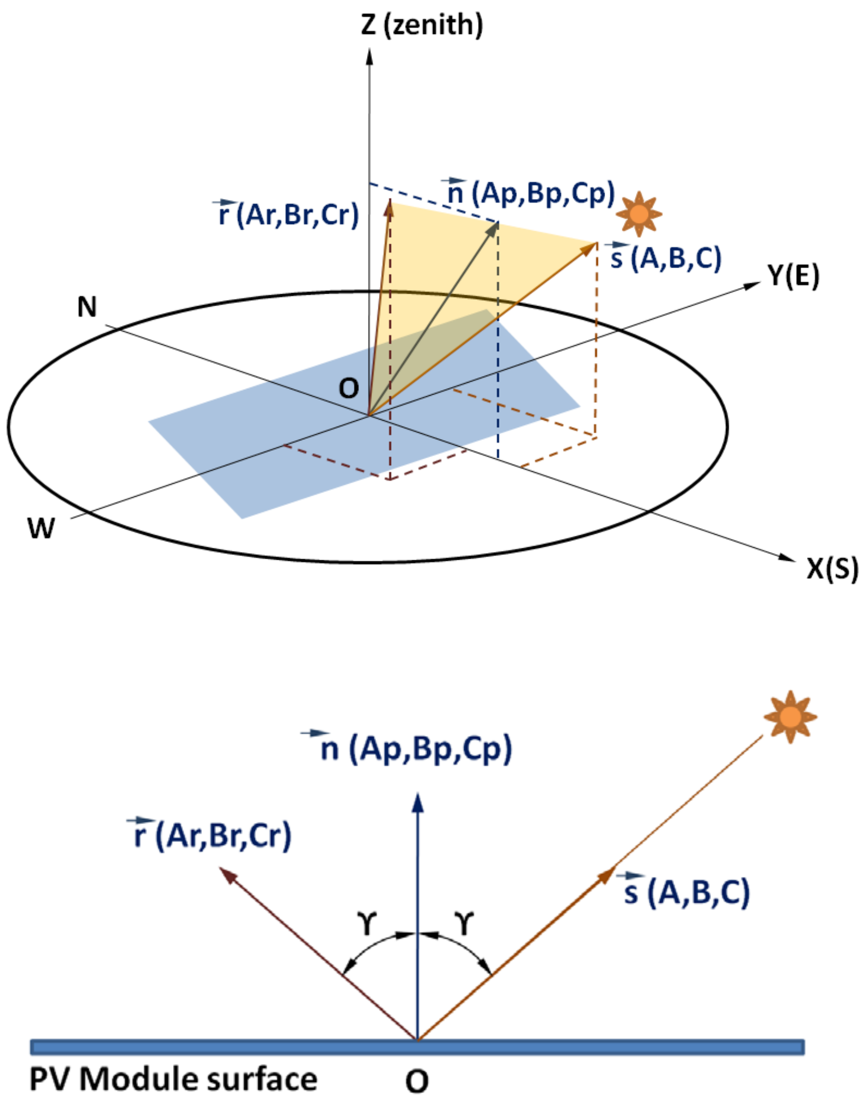



*Fig 8.- Reflecting surfaces – Notation for reflected beam vector*

A relevant variable in this figure is the incidence angle [ϒ], which measures the angle between the incident sun beam vector and the surface normal. No reflection can occur when the incidence angle is equal or larger than 90°. This situation will occur whenever the sun is behind the PV modules surface. The incidence angle can be calculated as per the dot product of unit vectors [s] and [n]:

$$\cos\gamma = \vec{s}\ \vec{n} = A\,A_p + B\,B_p + \ C\,C_p$$

The symmetric-reflected vector [r] is calculated as

$$\vec{r} = 2\ \cos\gamma\,\vec{n} - \ \vec{s}$$

and its Cartesian coordinates given by:

$$A_r = 2\ \cos\gamma\,A_p - A$$
$$B_r = 2\ \cos\gamma\,B_p - B$$
$$C_r = 2\ \cos\gamma\,C_p - C$$

For example, for the equinox day chosen the results for (Ar, Br, Cr) are plotted below in function of the hour of the day. Incidence angle cosine also included.

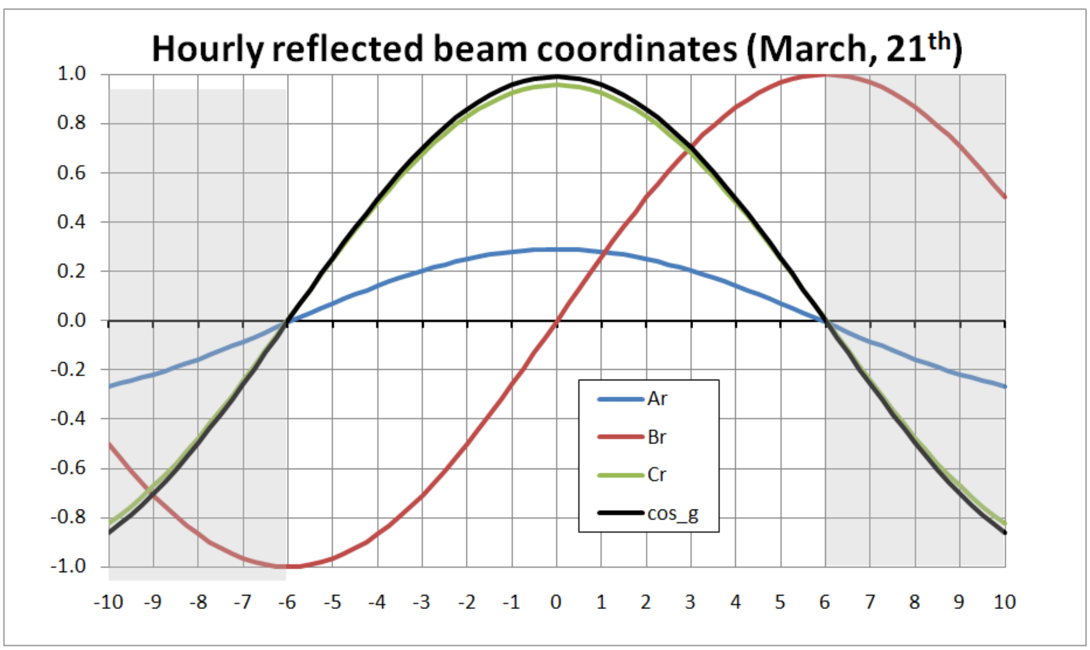



*Fig 9.- Reflected vector coordinates and incidence angle*

## 3.4 Flight plane and reflectivity at Calexico runway (fixed systems)

To define the location of relevant KVP it is hereby assumed that the approaching airplane follows a straight line contained in a vertical plane (the "flight plane") that also contains the runway axis (Fig. 10).

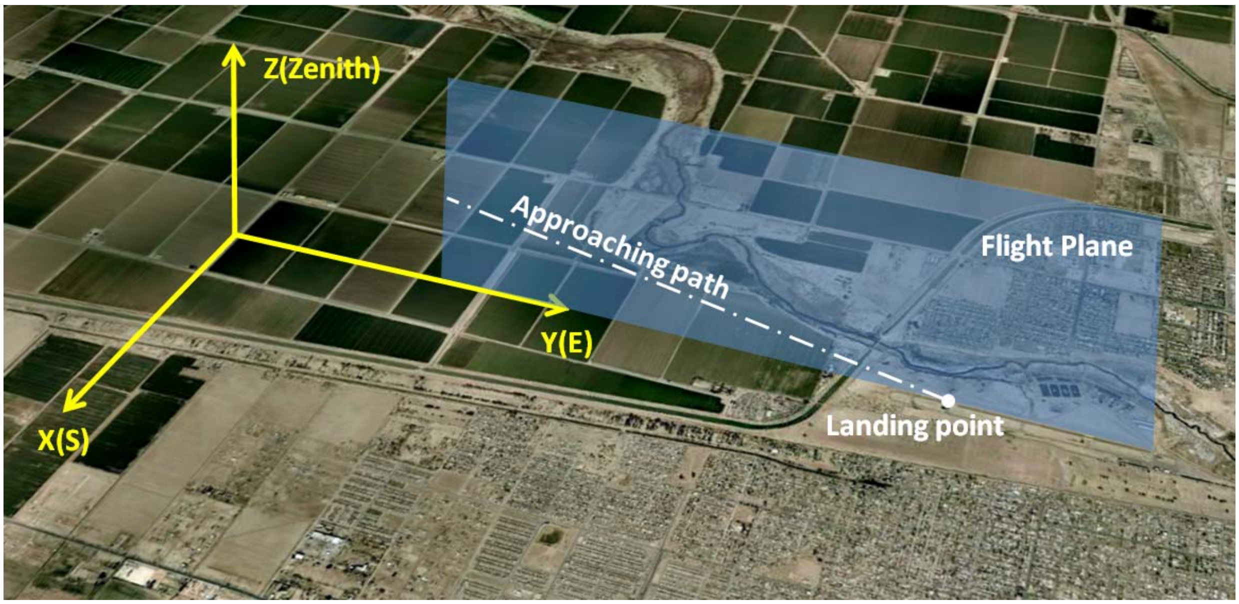



*Fig 10.- Geometry of approaching path*

The vertical flight plane, containing the approaching path, is defined by the following equation in the reference Cartesian axis system:

$$\Pi \equiv 0.9997\ x - 0.0239\ y = 0$$

The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

Runway azimut is 88.63°. Cartesian coordinates for any reflected beam r = (Ar, Br, Cr), if contained in the flight plane, shall satisfy the following condition (beam azimuth):

$$\frac{B_r}{A_r} = \tan\ 88.63° = 41.814$$

The angle between the horizontal plane and the reflected vector (reflection elevation angle) is given by

$$\tan \theta_r = \frac{C_r}{\sqrt{A_r^2 + B_r^2}}$$

Fig. 14 shows the hourly evolution of the above functions for a sample day (March, 2nd)

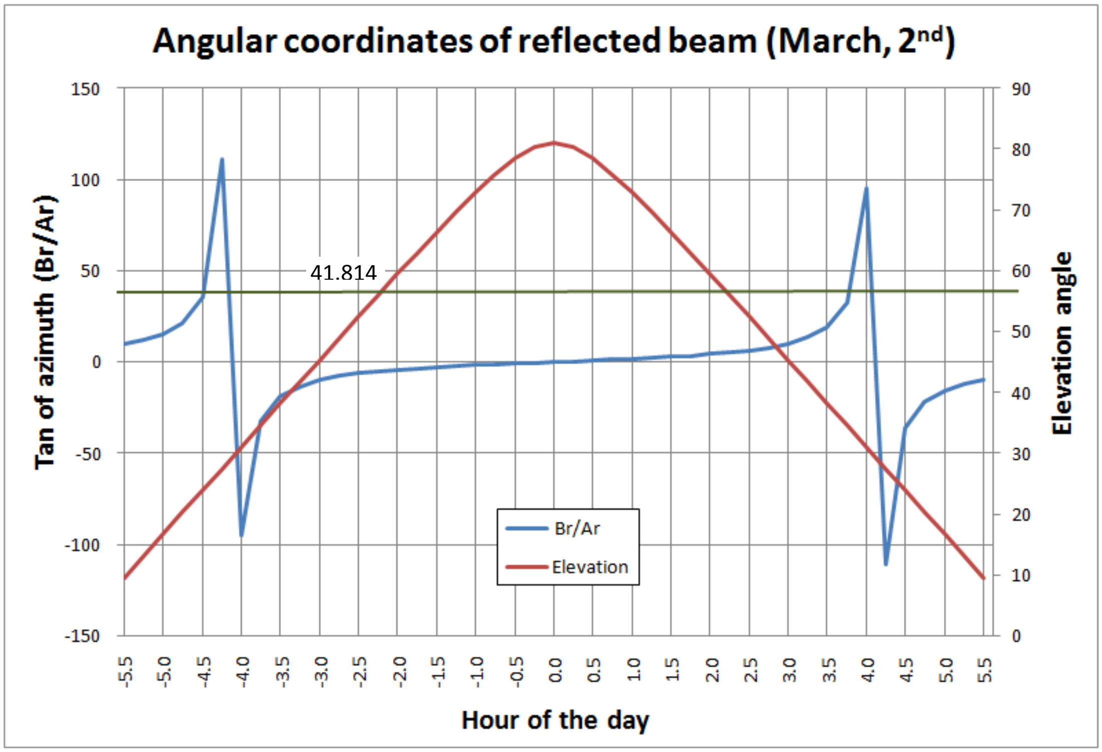
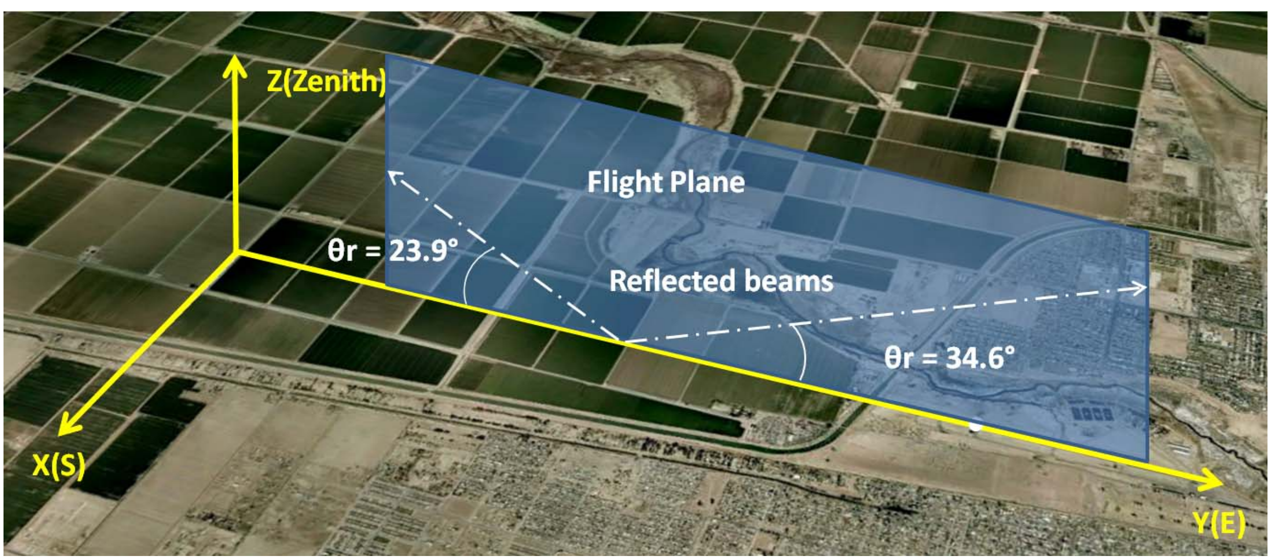



*Fig 14.- Angular coordinates of reflected beam (March, 2nd)*

It can be seen that the reflected beam will be contained in the flight plane at 07:30h (after sunrise) and at 15:45h (before sunset). The reflected beam will be pointing upwards with an angle of 23.9° and 34.6° respectively.



Obviously, the reflection held at 07:30 would affect airplanes landing Calexico from West, while the reflection held at 15:45h would afect airplanes landing or launching from East. In both cases, a long-term glint exposure would only occur if the airplanes were landing at the same particular angles (i.e., 23.9° and 34.6° respectively). It should be noted that normal landing angles are within the range of 3° and 6°, so in this particular day no risk of prolonged glint is possible.

The same procedure is repeated for all days in a year. Results in Fig.15 shows the elevation angle of the reflected beam in function of the day, whenever the in-plane condition occurs. Bandwith between estimated minimum and maximum airplane landing angles (3° and 6°) is superimposed :

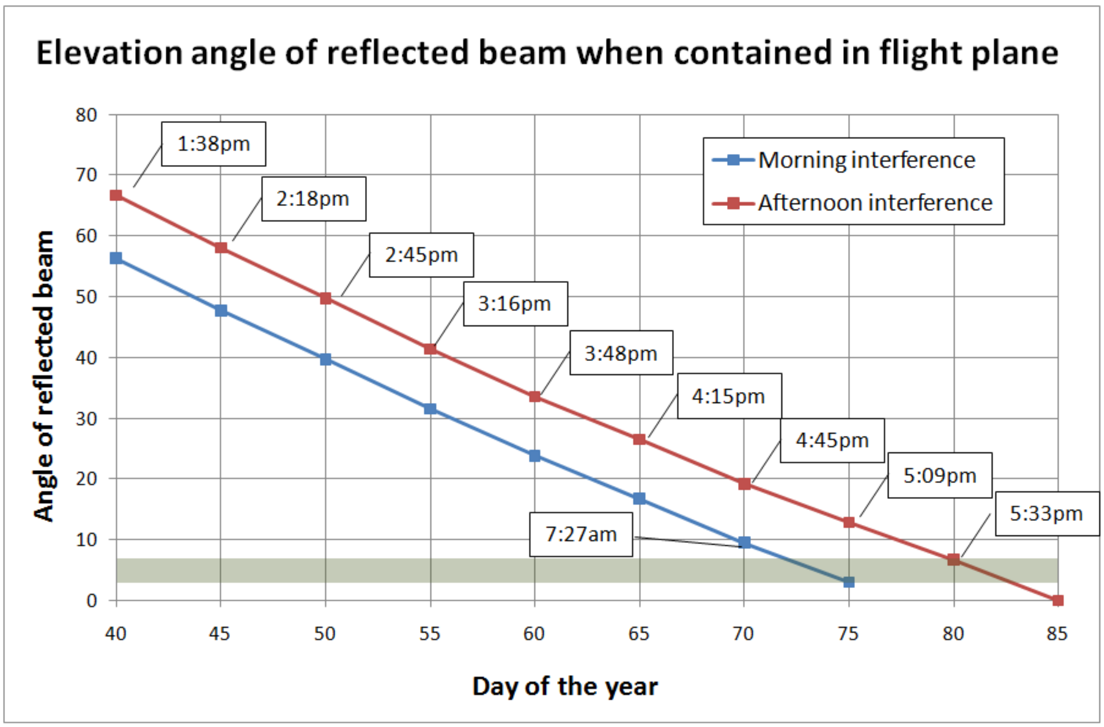



*Fig 15.- Reflected beam elevation angle and landing angles – Runway 29*

There are a few days in the year where there is an eventual risk of glint from the PV modules to landing airplanes. These particular days are 72 to 75 ($2^{nd}$ week of March - morning time) and 80 to 83 ($3^{rd}$ week of March - evening time). Because of yearly simmetry, the same occurs in mid-October.

Fig. 16 shows sun coordinates for a typical day in these periods (day 73). Interference with landing path occurs at around 07:37 hours, sun azimuth is -84° and elevation only 3°. Therefore airplanes reaching Calexico airport runway from the West end will have the sun disc just in front of them. It is considered that glint effect is neglegible when compared to direct sun light exposure, as in this case.

Similarly, planes landing or launching from the East at day (say) 82, will be facing the sun disc at sunset, and again the risk of glint is negligible when compared to the light intensity of direct sun.

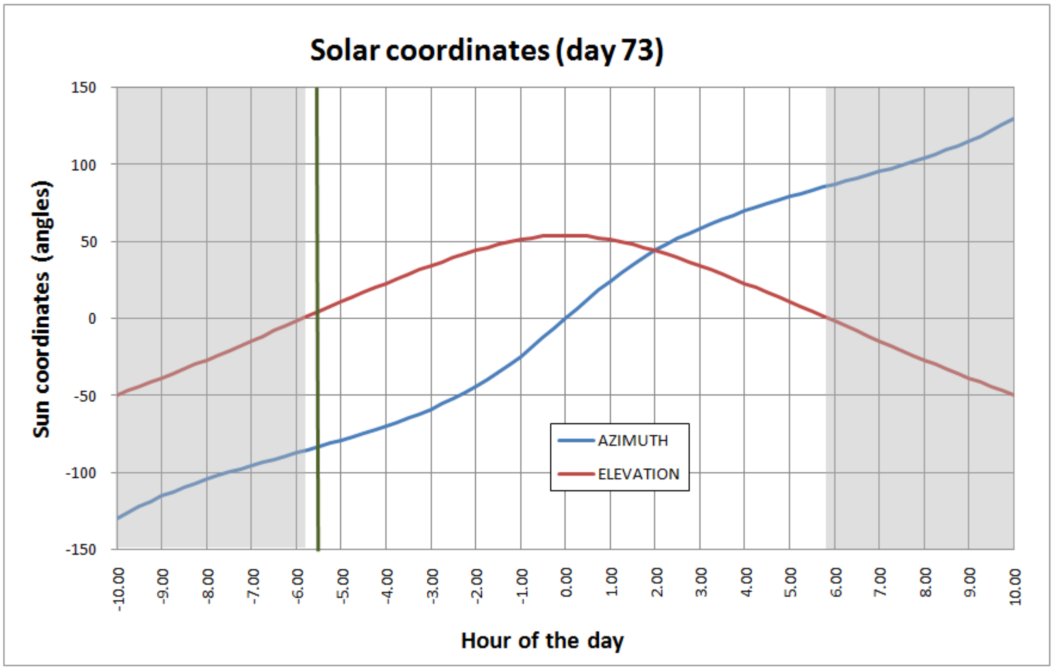
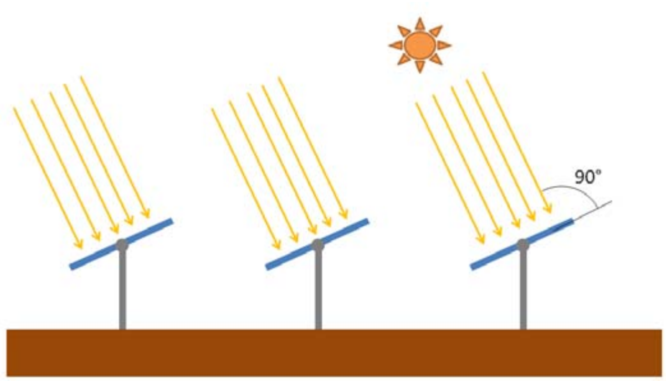



*Fig 16.- Sun postion for selected typical interference day – Green vertical line shows time of interference with airplane landing path.*

## 3.5 Reflection equations for horizontal axis trackers

Tracker systems are mechanical devices that continuously change the PV modules orientation with sun position, so to obtain the maximum irradiance at any time during the day. In particular, the horizontal axis trackers are oriented in North-South direction, so the modules attached to the horizontal rotating axis are inclined towards East during sunrise and are rotated towards West as the earth rotates.

Vector coordinates for the reflected beam are the same as described in paragraph 3.3, but in this case the vector perpendicular to the modules is not constant along the day, but rotating with the horizontal tracker axis. Target is to keep the incidence angle as close a zero as possible.



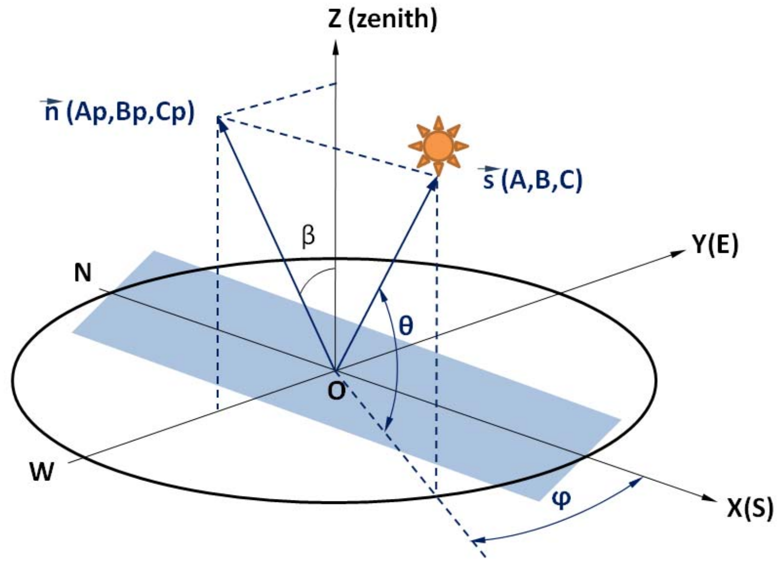



*Fig 17.- Normal vector to PV modules in an horizontal axis tracker*

Given the instantaneous rotation of the tracker as an angle (β), the normal vector n=(Ap, Bp, Cp) perpendicular to the plane of the modules is

$$A_p = 0$$
$$B_p = -\sin\beta$$
$$C_p = \cos\beta$$

The objective is to track for the minimum incidence angle (γ). This will occur also if the cosine of the incidence angle (γ) is a maximum:

$$\cos\gamma = \vec{s}\ \vec{n} = A\ A_p + B\ B_p + C\ C_p$$

this can be written as

$$\cos\gamma = -B\sin\beta + C\cos\beta$$

The minimum incidence angle occurs when

$$\frac{d\ (\cos\gamma)}{d\beta} = -B\cos\beta - C\sin\beta = 0 \qquad \tan\beta = -\frac{B}{C}$$

Which describes the rotation angle of the tracker in function of sun position, and hence the coordinates for the vector perpendicular to the plane of the PV modules.

### 3.5.1 Backtracking

At low sun elevation angles (i.e., sunrise and sunset), the trackers would be fully deployed and mutual shading between successive rows of modules will occur. To avoid this situation, the tracking control system has the so called backtracking algorithm, which defines the tracker rotation angle so to avoid this mutual shading. When the backtracking is active, the tracker will not rotate to follow the sun path, but to avoid mutual shading between rows. This occurs every day early in the morning and late in the evening, and depends on the PV plant geometry, day of the year and latitude.

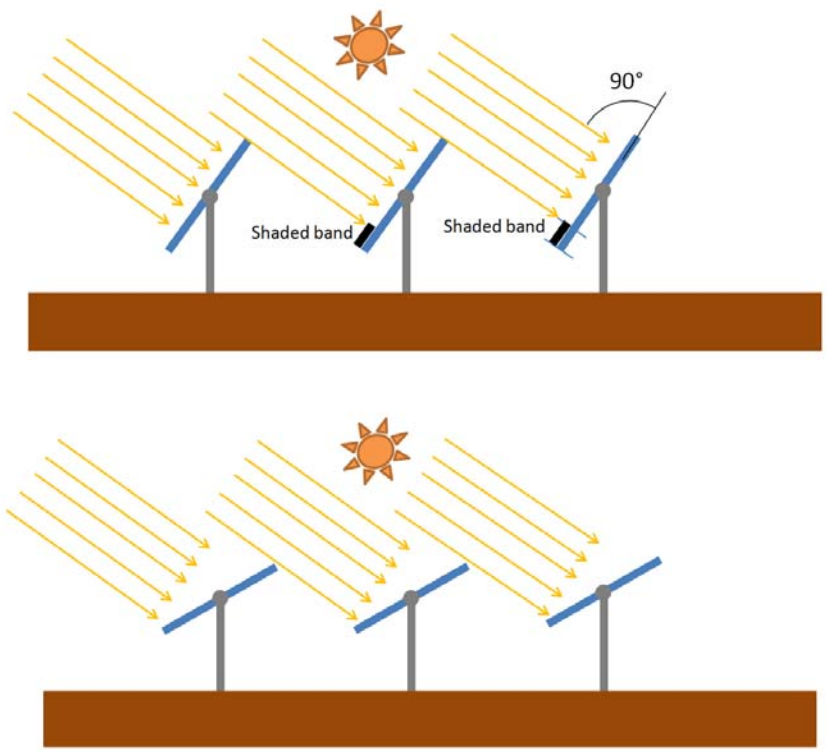



*Fig 18.- Above: Mutual shading without backtracking.*
*Below: Backtrackin corrected incidence angle to avoid mutual shading*

The tracker angle when the backtracking is active is given by the following equation:

$$\tan\theta = \frac{L\ sin\beta}{p - Lcos\beta}$$

Where [L] is the length of the modules (6.46 ft) and [p] is the pitch between tracker rows (19.6 ft). Maximum tracker angle is ±45° for mechanical and constructive reasons.

Fig. 19 shows the tracker angle, together with sun elevation angle for a sample day (March, 21st).

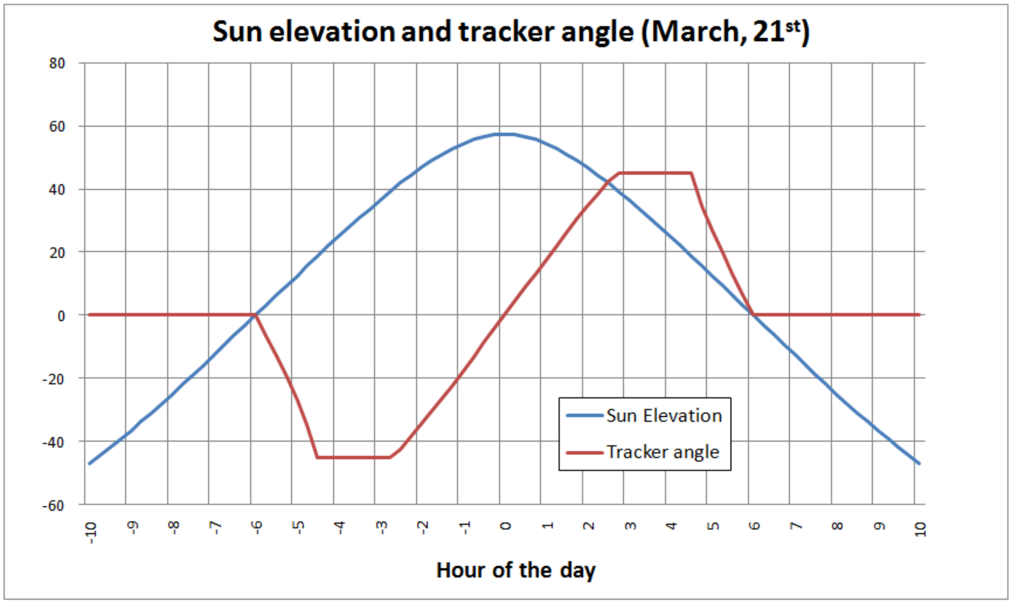



*Fig 19.- Tracker angle on a sample day*

Cartesian coordinates of the reflected beam, and incidence angle are shown in Fig. 20,

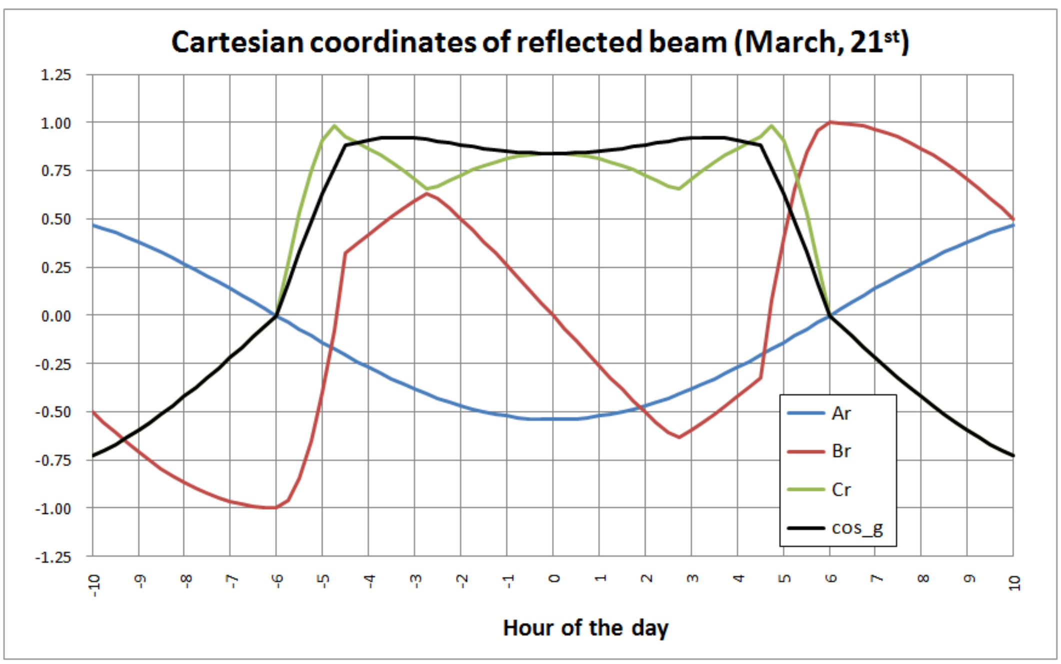



*Fig 20.- Cartesian coordinates for reflected beam on a sample day. Incidence angle is very low, thus optimizing irradiance on PV modules with trackers.*

## 3.6 Reflectivity analysis with horizontal axis trackers at Calexico

The procedure described in 3.4 is repeated now for the moving reflecting surfaces. The flight plane contains the PV plant, as shown in Fig.3. Several days along the year and at certain hours, a reflected beam vector will be contained in the flight plane, but relevant glint might occur only if the elevation angle of the reflected beam is coincident with the flight approaching angle, in either East or West directions.

As an example, Fig. 21 shows the azimuth and elevation angle of the reflected beam. The green line defines the flight-plane azimuth condition for Calexico, thus the reflected beam will be contained in this particular plane at 8:45am and 3:00pm, but in both cases the beam elevation angle is well over 40°, so there is no risk for glint.

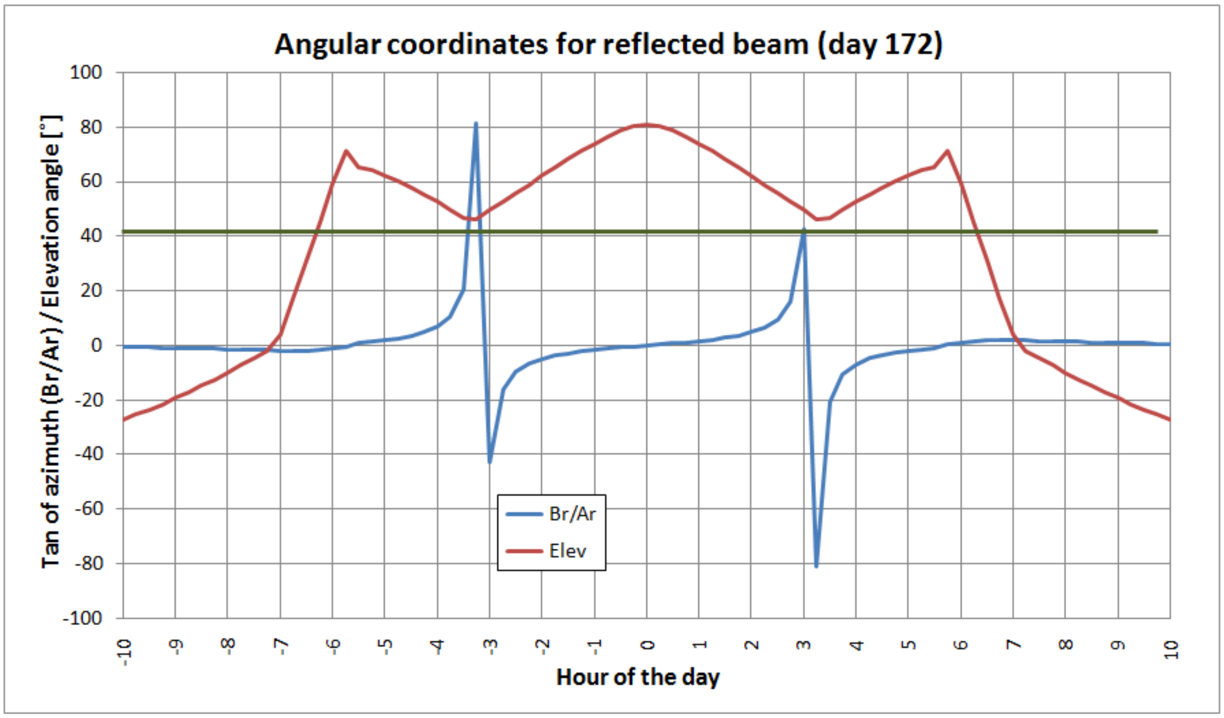



*Fig 21.- Angular coordinates for reflected beam (day 172)*

The same calculation is repeated for a complete year and results shown in Fig. 22.

It can be seen that whenever the reflected beam is contained in the flight-plane, its elevation angle is very far from the usual approaching or launching angles to the airport, so there is no risk of glint with trackers.

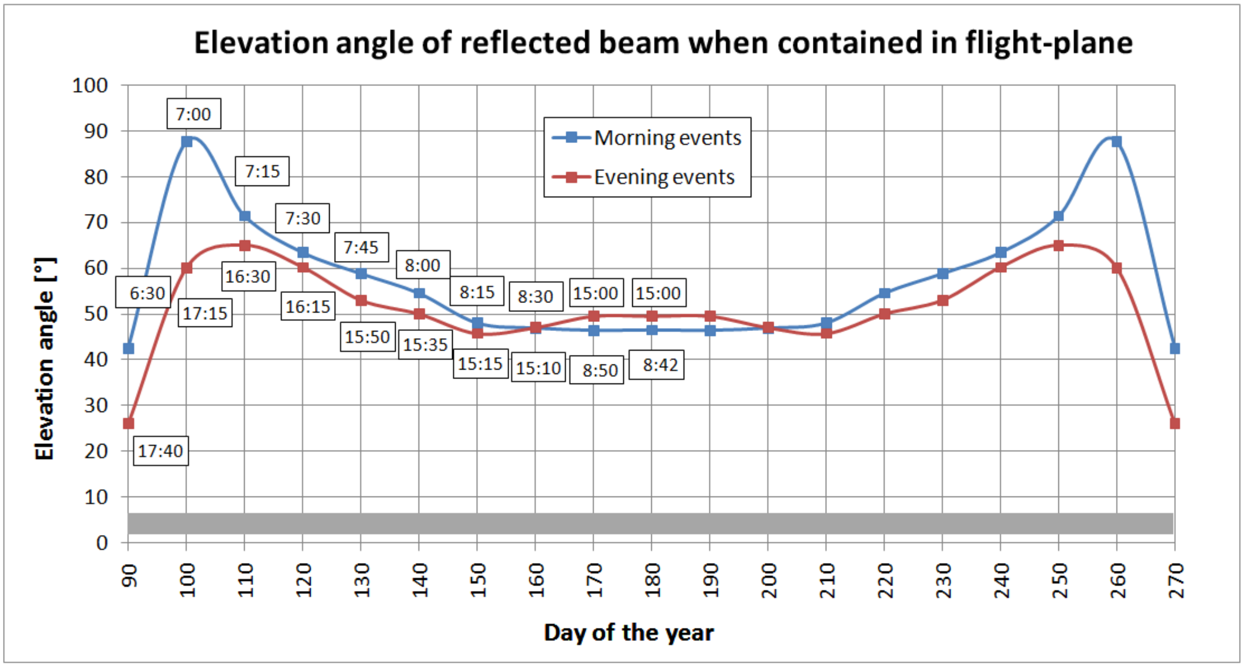



*Fig 21.- One year results for elevation angles of reflected beam when contained in the flight plane. For the six month period from October to March the reflected beam is never contained in the flight-plane.*

# 4 Conclusion

PV installations are based on photovoltaic modules with low reflectivity characteristics. Just 10% of the incident radiation is reflected, but this might produce some glint to KVPs. For this Project, it is considered that airplanes landing at or taking-off from Calexico airport might be exposed to glint.

To determine the glint risk, a geometric analysis is done for both scenarios: Fixed tilt PV modules and Horizontal Axis trackers. The analysis is conducted for a complete year in intervals of 15 minutes (that is 35040 points). All mathematical expressions hereby described are implemented in a computer routine.

In the case of fixed tilt PV fields it has been demonstrated that, in the few cases when there is some risk of glint by PV modules, the airplane will also be directly facing the sun disk, so it can be concluded that glint from PV modules will not have any relevant effect on airplanes' visibility, nor deteriorate the actual approaching or launching flight conditions.

If the PV plant is built with horizontal axis tracking technology, the eventual reflected beam would have a high elevation angle (that is, pointing upwards), so no interference with approaching or launching airplanes from Calexico airport will ever occur.

The same conclusions can be extended to other tracking technologies (single inclined axis or double axis trackers). With these devices, the tracking efficiency is higher than with horizontal axis trackers, therefore the incident angle is even lower, and the reflected beam will be pointing the sun disk more closely. Risk for glint when landing of launching might theoretically occur only at low sun elevation angles (i.e., sunrise or sunset); however, during these particular hours the backtracking technology modifies the tracking algorithm to avoid mutual shading thus re-orientating the reflected beams upwards, far from the flight path.

It is concluded that this Project will not have any relevant glint effect for airplanes landing at or taking-off from Calexico airport. This is also applicable regardless of whether the Project is built in one, two or more phases.

## Potential Impacts from Reflection of Proposed Mount Signal Solar Farm I (82 LV)
Draft Date: May 24, 2011

**KEY FINDINGS**

- Based on the geometric configuration of the panels relative to the path of the sun and the inherently low reflectively of flat-plate photovoltaic modules it is highly unlikely that the proposed projects will result in hazardous glare conditions.
- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection well above the nearby roads and the built environment.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Mount Signal Solar Farm I which is located 2.5 miles west of Calexico in Imperial County, California. The project site is comprised of four parcels of land with a total area of 1,403 acres. See Appendix A for aerial photographs of the site.

The proposed project is a 200-megawatt ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the Mount Signal Solar Farm I project on nearby roads and a residential neighborhood on the western edge of Mexicali, Mexico. The reflection impacts on aircrafts using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

### Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules. Photovoltaic panels are using the absorbed energy in two ways; 1) the panels generate electricity, and 2) the mass of the panels heat up.

In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.
[2] Ibid.

## Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around .10.[3] By comparison, sand has an albedo between .15 and .45 and agricultural vegetation has an albedo between .18 and .25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

## Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs mid-day on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 1 below). The potential impact at that moment is the best proxy for maximum impact overall.

During summer solstice at the proposed projects' latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is highly unlikely that any objects in the built environment near the project site would be adversely affected by a direct reflection of sunlight from this angle, including vehicles traveling on nearby roads or residential neighborhoods on the western edge of Mexicali. Indeed, there are no structures of combined height and proximity to experience this direct reflection.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed projects' latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

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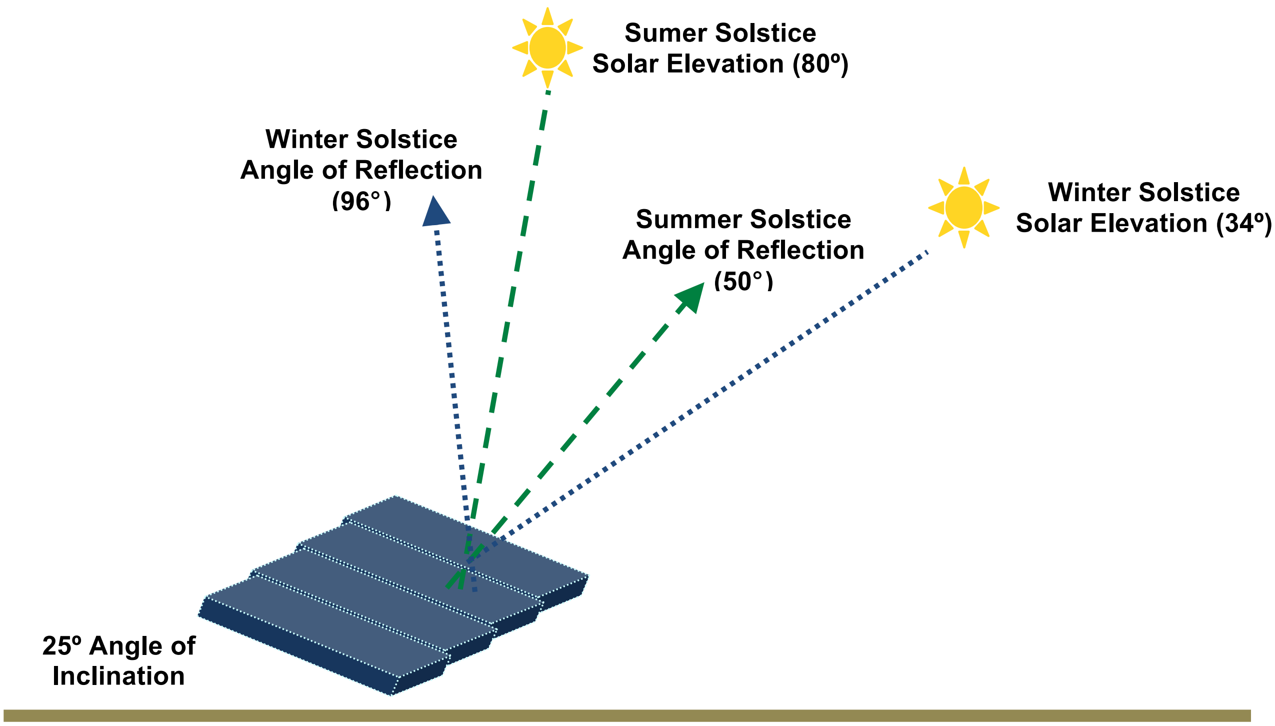
[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 33.16 degrees north. A copy of the chart is attached at the end of this document.

**Figure 1:** The range of the sun's angle-of-reflection depending on the time of year.

## Variation in the Angle of Reflection Throughout the Year




The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 30 feet (the approximate distance from the southern edge the Parcel II array to the edge of the utility road to the south), the height of the reflected sunlight from the array would exceed 36 feet in elevation, well above the California truck height limit of 14 feet. It's important to note that roads in the immediate vicinity of the arrays are non-paved utility roads, not major transportation corridors and as such is not expected to support significant passenger or commercial traffic.

The built structure closest to the Mount Signal Solar Farm I site is a single residence 0.4 of a mile due south (off of Rockwood Road) off the southeastern corner of Parcel III (lot 052-210-016). At this distance, the height of direct reflection is over 2,200 feet (or ~0.4 of a mile). The closest group of structures to the Mount Signal Solar Farm I is a residential neighborhood on the western edge of Mexicali, Mexico. These homes are 0.9 of a mile due south from the southern edge of the array in Parcel II (specifically lots 059-130-004 and 059-130-005). At this distance, the height of direct reflection is over 5,300 feet (or ~1 mile).

Figure 2 shows Parcel I and II of the Mount Signal Solar Farm and points A through F indicating different distances from the panels. Figure 3 shows the corresponding elevation of direct reflection at each point indicated in Figure 2.

**Figure 2:** Map of the points listed in Figure 3 and the "on the ground" distance from each point to the array.

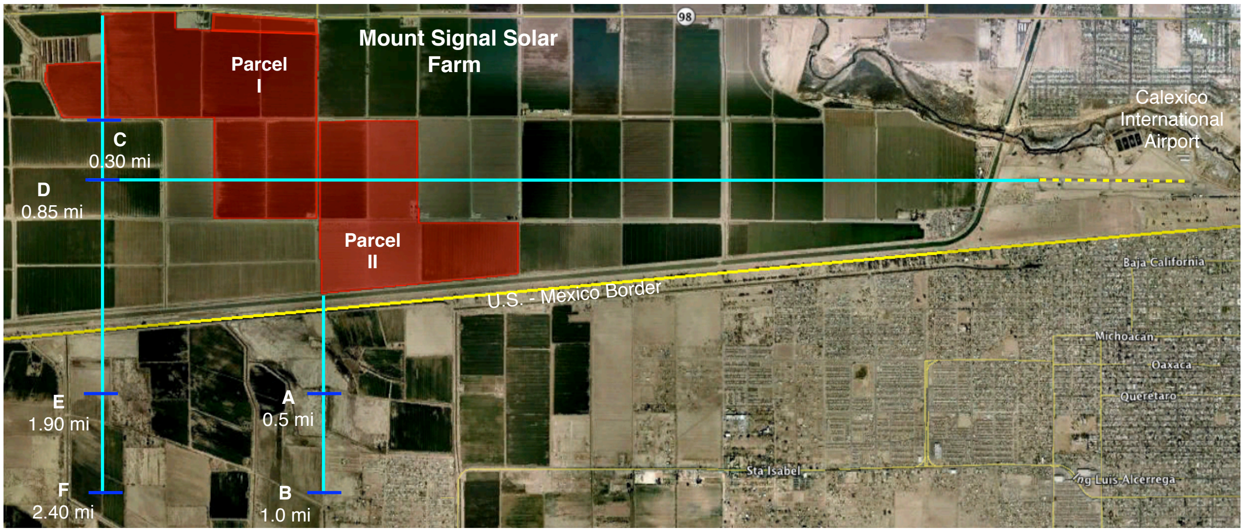



**Figure 3:** Elevation of direct reflection for the points show on Figure 2.

| Point on Figure 2 | Elevation of Direct Reflection | |
|---|---|---|
| | miles | feet |
| A | 0.60 | 3,147 |
| B | 1.19 | 6,294 |
| C | 0.36 | 1,890 |
| D | 1.01 | 5,349 |
| E | 2.26 | 11,954 |
| F | 2.86 | 15,101 |

### Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[6]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[7]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (an any indirect reflection).

### Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array, the greatest potential for a low angle of reflection that might impact the built environment occurs mid-day on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At mid-day on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

[6] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see "Panache Valley Solar Farm Project Glint and Glare Study" (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and "Topaz Solar Farm Reflection Study" (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).

[7] TrinaSolar. "Reflection Coefficient of Trina Solar Modules." Personal communication with Thomas Houghton, June 30, 2010.

## Appendix A: Glare Analysis Explanation

### Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[8] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

**Figure 4:** Angle of direct reflection on summer solstice (June 21).

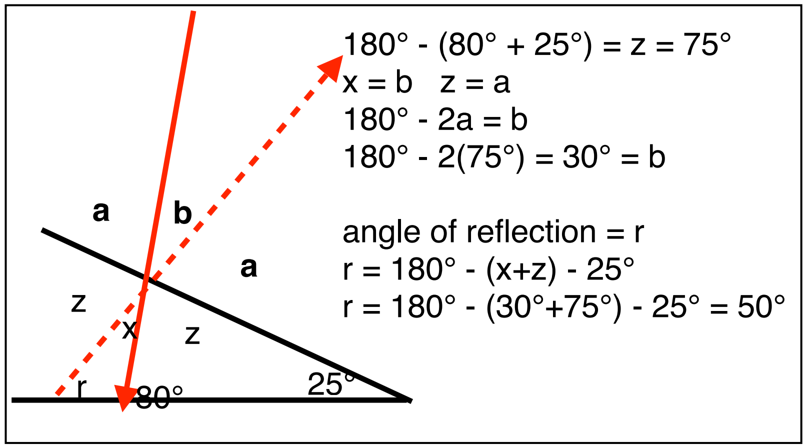
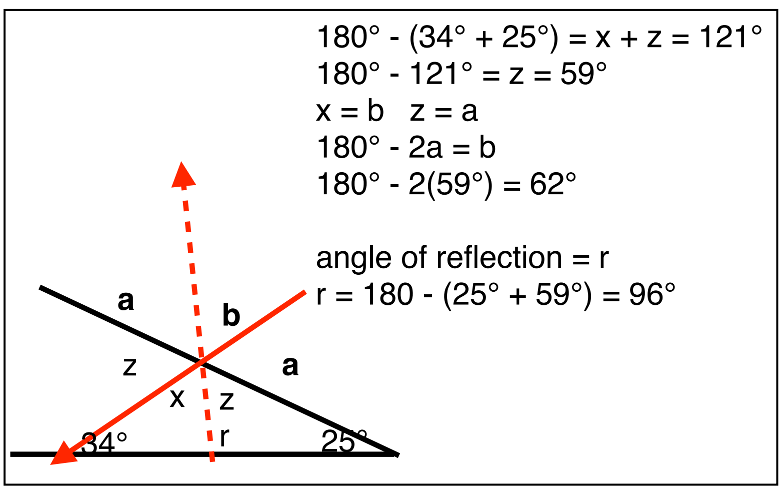



Figure 4 depicts this reflection. All angles within a triangle add up to 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

**Figure 5:** Angle of direct reflection on winter solstice (Dec. 21).



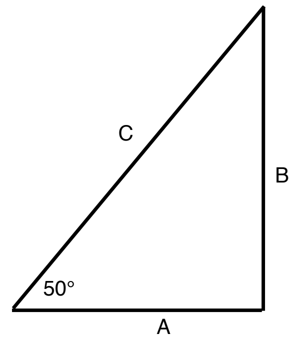

Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point (see the Figure 5 to the left, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[8] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

**Determining the Height of Reflection**

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Mount Signal Solar Farm. Figure 6 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

**Figure 6:** Calculation to determine direct reflection.

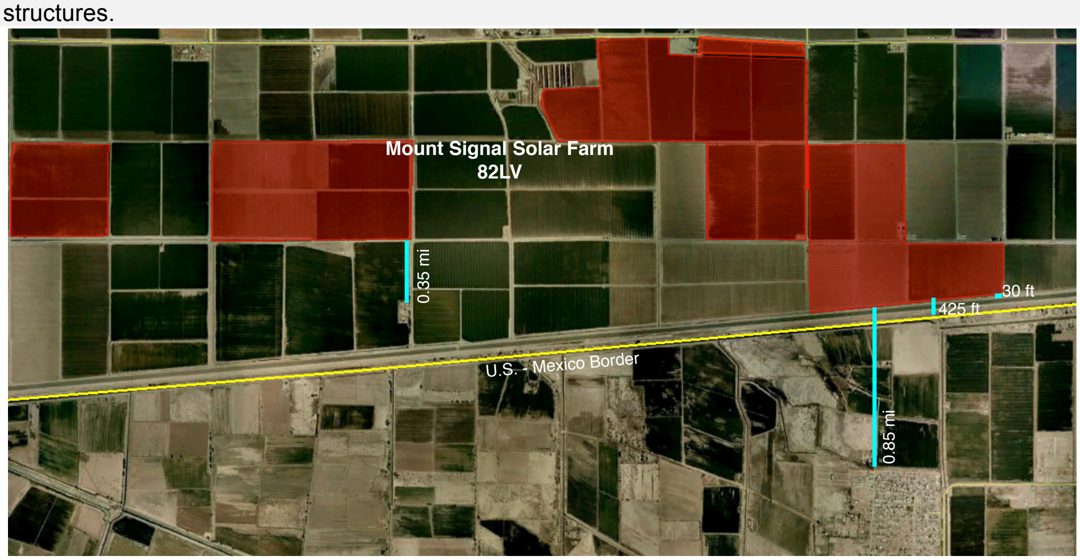



$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 7 is an aerial picture of the sited Mount Signal Solar Farm from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico Border (yellow line) as well as the four parcels which serve as the boundaries for the panel arrays in this project. Figure 5 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 4 describe the height of the direct reflection at the various distances shown by the blue lines.

**Figure 7:** Aerial image of the Mount Signal Solar Farm I project array locations and distances to nearby built structures.




- At 30 feet from the solar panels the height of the reflection is at 35.8 feet or higher (depending on the time of year). This is the approximate distance from the panels to the utlity road that runs parrellel to the southern edge of Parcel II.

- At 425 feet from the solar panels the height of the reflection is 506.5 feet or higher. This is the distance from the southern edge of Parcel II to the Mexican boarder.

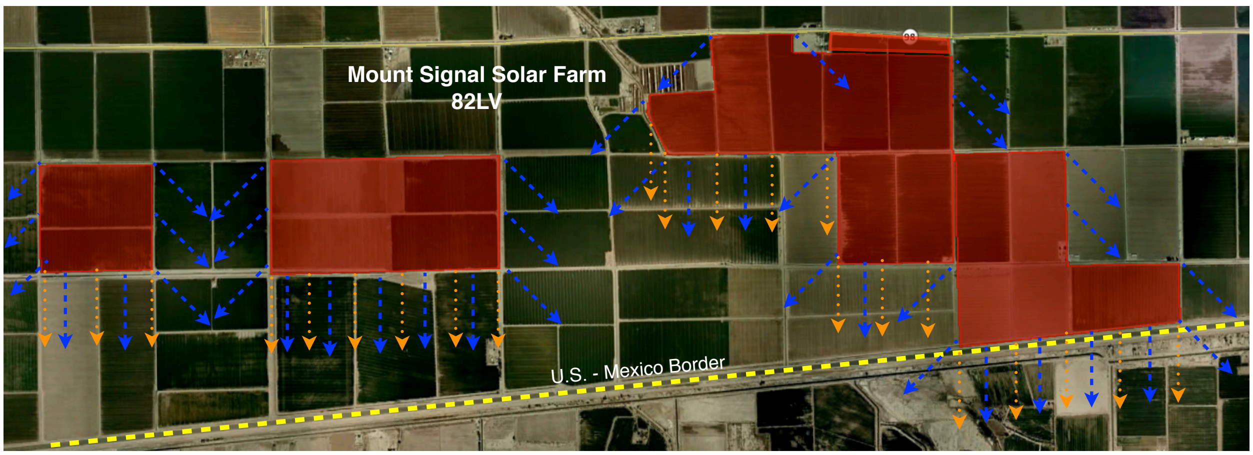
- At 0.35 miles from the solar panels the height of the reflection is 0.417 miles (2,202 feet) or higher. This is the distance from the southern edge of Parcel III to the closest building.

- At 0.85 miles from the solar panels the height of the reflection is 1.013 miles (5,349 feet) or higher. This is the distance from the southern edge of Parcel III to the closest group of buildings (a neighborhood on the far western edge of Mexicali, Mexico).

## Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

**Figure 8:** Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).



# Visualization Study

# Mount Signal Solar Farm I

Visualizations by

modative

Design

Develop

Build


Final design and location/route may be revised prior to issuance of permits

Viewshed Locations

**Mount Signal Solar Farm I (82LV)**

Key Plan

**date:** 6/30/11
**project:** 82LV

KEY

Existing

Proposed

Final design and location/route may be revised prior to issuance of permits

Looking South East Along Highway 98

**Mount Signal Solar Farm I (82LV)**

**date:** 6/30/11
**project:** 82LV

Existing

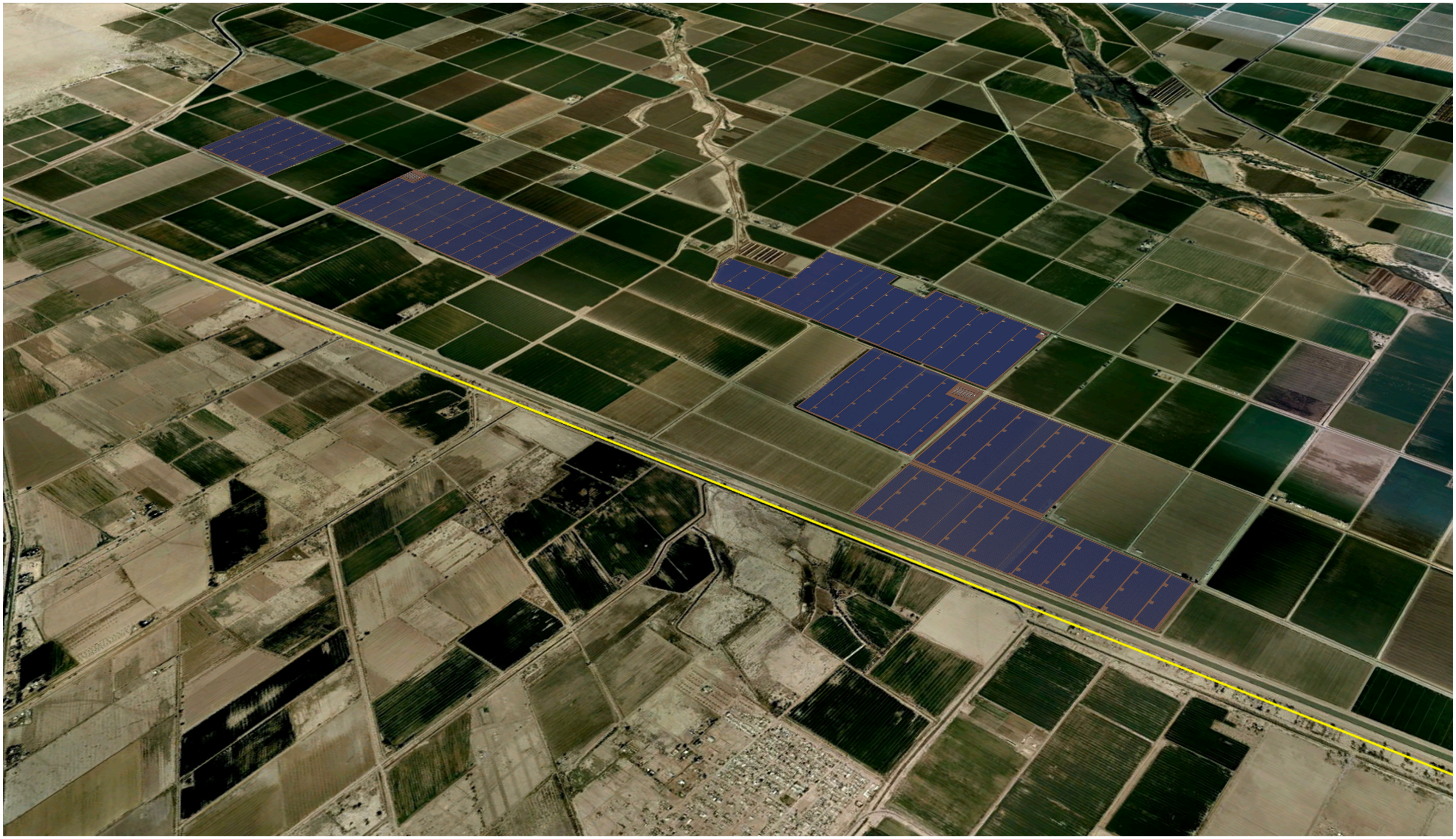
Proposed

Final design and location/route may be revised prior to issuance of permits

Looking North-West Along Anza Road

**Mount Signal Solar Farm I (82LV)**

**date:** 6/30/11
**project:** 82LV



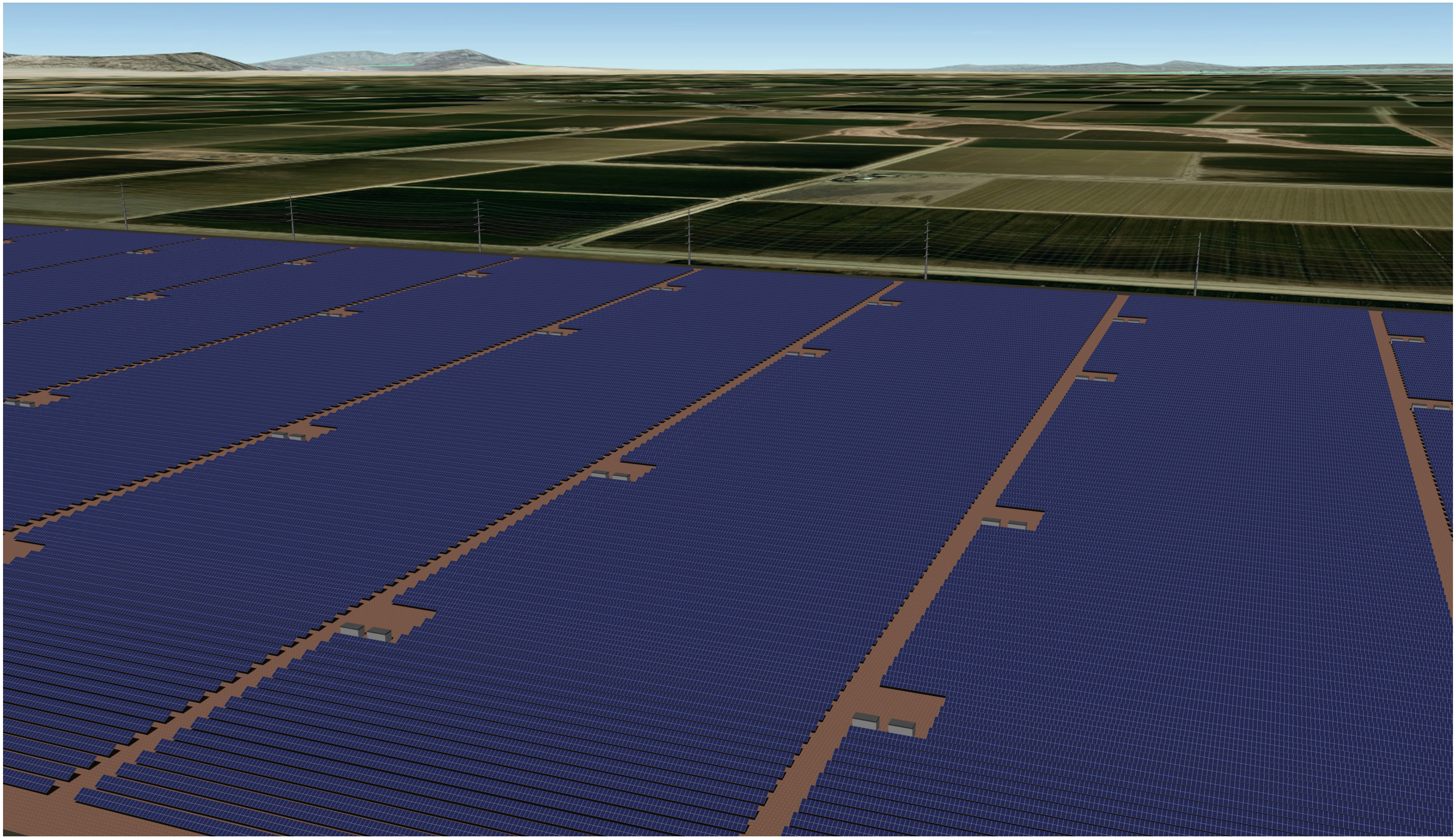
Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

**Mount Signal Solar Farm I (82LV)**

**date:** 6/30/11
**project:** 82LV



Proposed

Final design and location/route may be revised prior to issuance of permits

Overhead View

## Mount Signal Solar Farm I (82LV)

**date:** 6/30/11
**project:** 82LV