SUNPOWER

Oasis C7 CPV Tracker

Glint and Glare Analysis

Abstract

Assessment of potential hazards from glint and glare from concentrated solar installations is an important requirement for public safety. This paper discusses the glint and glare levels for the C7 tracker compared to those of flat solar panel used in Oasis C1, smooth water surfaces and solar glass. We find that the glint level for C7 (direct reflection from mirrors) during worst case scenario will be below the glint level from smooth water and solar glass for distances greater than approximately 12 meters (m) away from the system and will be below SunPower AR coated flat panels (C1) for distances greater than approximately 20 m. The glare level (diffuse reflection from the receiver) will be below SunPower flat panel AR coated (C1) for distances greater than approx. 0.55m from the receiver. Additionally, C7 receivers are coated with anti-reflection coatings further minimizing glare from the receiver as per mitigation measure MM4.1-6LA. Finally, C7 glint and glare levels are below thresholds typically used to assess glare and glint hazard in concentrated solar systems at distance beyond 0.3m from the focal zone.

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01	Modification to “meters” and (m)	06/22/12	Amine. B
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Introduction:

Assessment of potential hazards from glint and glare from concentrating solar installations is an important requirement for public safety. Glint or spectral highlight, defined as a momentary flash of light can cause temporary blindness (flash blindness) and even permanent eye damage (retinal burn) during extended exposure or excessive light intensity. Glare is defined as a continuous source of excessive light intensity relative to ambient lighting. Neighboring activity to a concentrated solar installation such as overhead flight, motorists driving alongside the site or people working in neighboring buildings can be subject to such conditions. (1)

The purpose of this paper is to analyze the various conditions at which glint and glare can occur in the SunPower C7 CPV tracking system and assess their potential hazard. C7 glint and glare levels will be compared to levels from smooth water, and to solar glass and anti-reflection coated glass, which is found in SunPower flat panels.

Various glint and glare analyses have been conducted for concentrating solar technology such as parabolic dish, linear concentrators and solar towers. Each one of them has been found to have safe levels for glint and glare and have been deemed as non-hazards when compared to typical safety metrics used in concentrated solar glint and glare analysis discussed below (1). The SunPower C7 system employs linear concentrator reflectors with parabolic profile, much like reflectors used for CSP projects, with the main difference being the much shorter focal length, which makes them safer from a glint and glare perspective.

Safety Metrics:

In their SolarPACES 2009 publication: *Hazard Analyses of Glint and Glare from Concentrating Solar Power Plants* (1) Ho et al discuss several safety metrics used to determine acceptable limits for glint and glare. Basing their discussion on ocular irradiation levels causing permanent damage to the retina, cornea and conjunctiva they have summarized acceptable exposure levels from different sources.

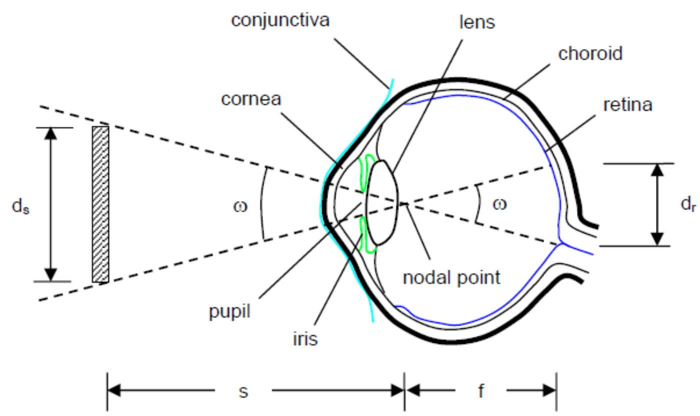


Figure 1: Image projected onto the retina of a human eye (1)

Figure 1 above shows an illustration of the human eye and how an image is projected onto the retina. The irradiance level at the retina Er is significantly higher than the irradiance level seen at the cornea Ec due the lensing effect of the human eye's lens. Using retinal burn data and maximum permissible retinal irradiance levels from Sliney and Freasier (2), Brumleve (3) (4) developed a convenient metric for safe retinal irradiance (Ers) based on retinal image size (dr), assuming circular images and a 0.15 sec exposure (typical blink response) (1). One can calculate the safe level of irradiance at the cornea (Ecs) through the following relationship:

$$Ecs = 0.0125\ Ers$$

In the example of viewing the sun directly the safe corneal irradiance is Ecs = 1600 W/m^2.

Similarly, Ho et al discuss another method used for safe ocular irradiance used in the ASNI 2000 standard. According to this method, the maximum safe corneal irradiance for viewing the sun directly is 5000 W/m^2.

Finally, Carrizo Energy Solar Farm glint and glare study uses an allowable light intensity exposure of 4500 W/m^2 (5)

Safety Metric	**Threshold**
Safe Corneal Irradiance Values from Brumleve (1)	Ecs = 1600 W/m^2
ANSI 2000 standard (Assume 0.15 – 0.2s exposure) (1)	Ecs= 5000 W/m^2
Carrizo Energy Solar Farm (5)	Ecs= 4500 W/m^2

Comparing glint and glare of system to typical levels seen from smooth water or glass is an additional metric used in determining glint and glare safety. Figure 2 below shows the reflected energy percentage of some common reflective surfaces. Light beam physics dictates a relationship between incidence angle and the percent of energy reflected from the surface, with 0 degree (normal) incidence reflecting the least amount of energy. In the case of C7 the reflective optics consist of mirrors with more than 94% reflectivity, however, because of their parabolic curvature, they act as light diffusers at distances exceeding their focal length. One can compare the percentage of light intensity relative to the distance from mirrors to the percentage energy level reflected at 0 degree from the surfaced in the figure below, to yield a conservative comparison of glint from the C7 system relative to smooth water and flat solar panels in their least reflective state.

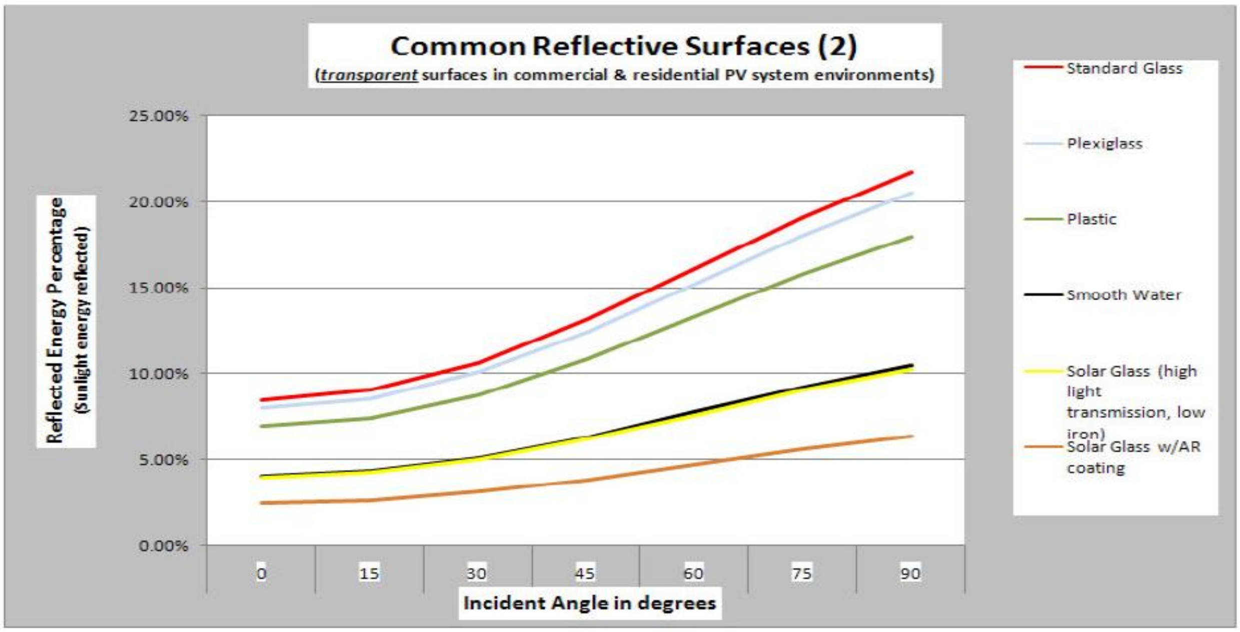


Figure 2: Reflected Percentage of Solar Energy as a function of incident angle for common reflective surfaces (6)

SunPower C7 CPV Tracker:

Description:

The SunPower C7 tracker uses parabolic shaped mirrors to reflect incident light onto a receiver consisting of photovoltaic cells and anti-reflection coated front glass. The concentration ratio chosen for this design is 7, whereby incident light is concentrated nominally 7 times when it reaches the target. Light can actually be concentrated about 11 times due to the beam width when it is reaches the receiver being narrower than the cells width in the receiver. Figure 3 below shows a ray tracing simulation of the 7x concentrator, which has a nominal focal distance of f = 0.209775 m. Incident light is reflected on the receiver which is opaque and oversized and thus captures 100% of reflected light.

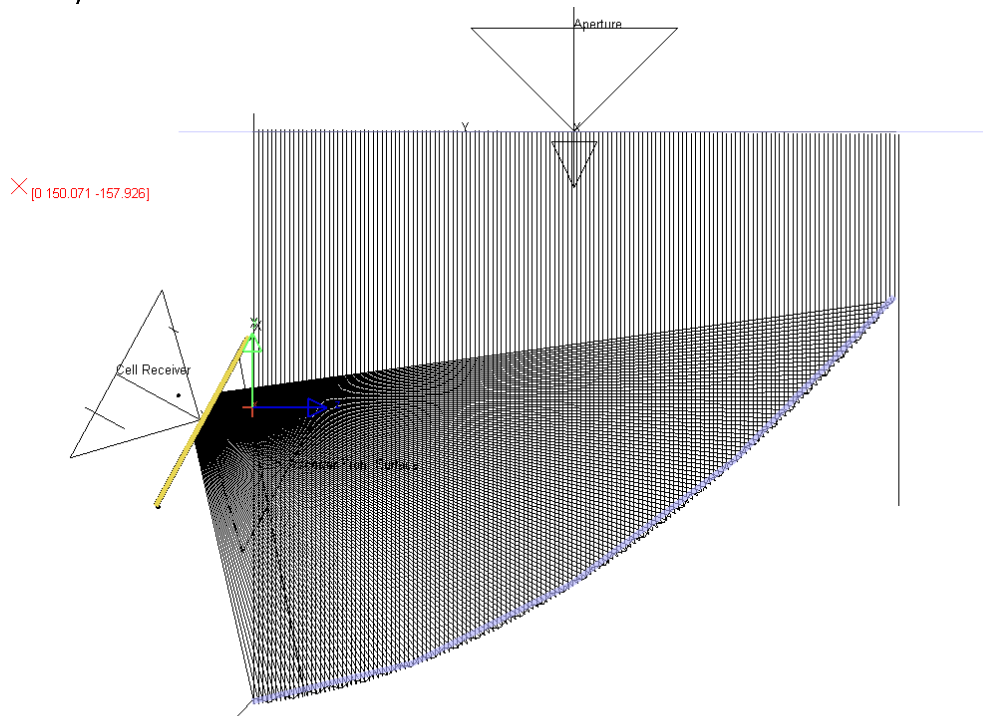


Figure 3: Illustration of SunPower 7X concentrating Reflector.

The tracking system is shown in Figure 4 below, while parabolic linear concentrators similar to CSP mirrors are the main optics, the positioning of the C7 mirrors is unique. Three mirror/ receiver modules are positioned symmetrically east and west of the torque tube. During operation concentrated light from the reflectors will be directed at the receivers. Potential glare from light reflecting off the receiver is minimal but will be analyzed below.

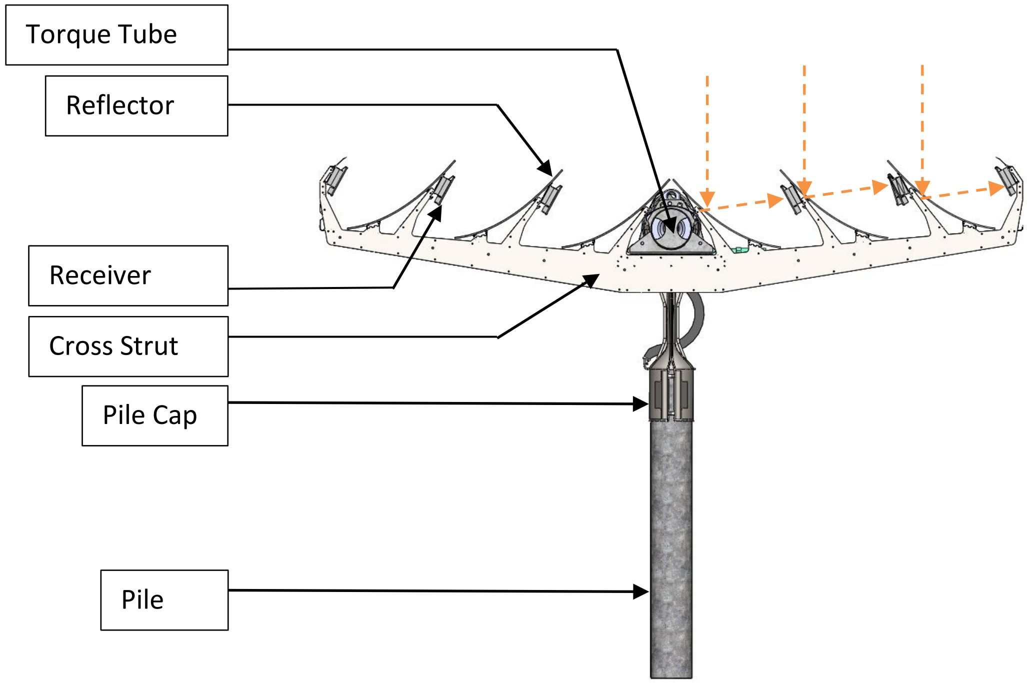


Figure 4: Side view of SunPower C7 tracking system (stow position)

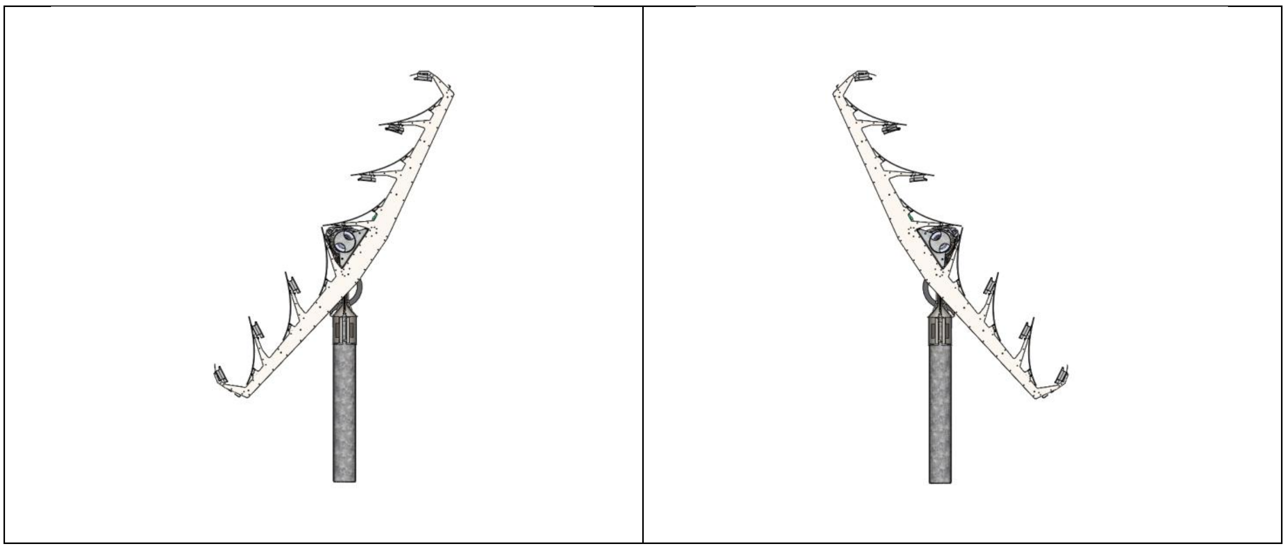


Figure 5: Side view of the C7 tracker in the East (left) and West (right) positions.

Glint Analysis:

Defining glint as the specular reflection of light incident on the reflectors, one can estimate the level of glint intensity seen by an observer as a function of distance from the focal point. From Figure 6 below, it becomes apparent that at a distance equal to the focal length away from the focal point the light intensity is equal to the incident light intensity on the reflector. In other words, at about a distance d = 0.210 m from the focal point an observer looking at the reflectors will see a light intensity equal to looking at the sun directly.

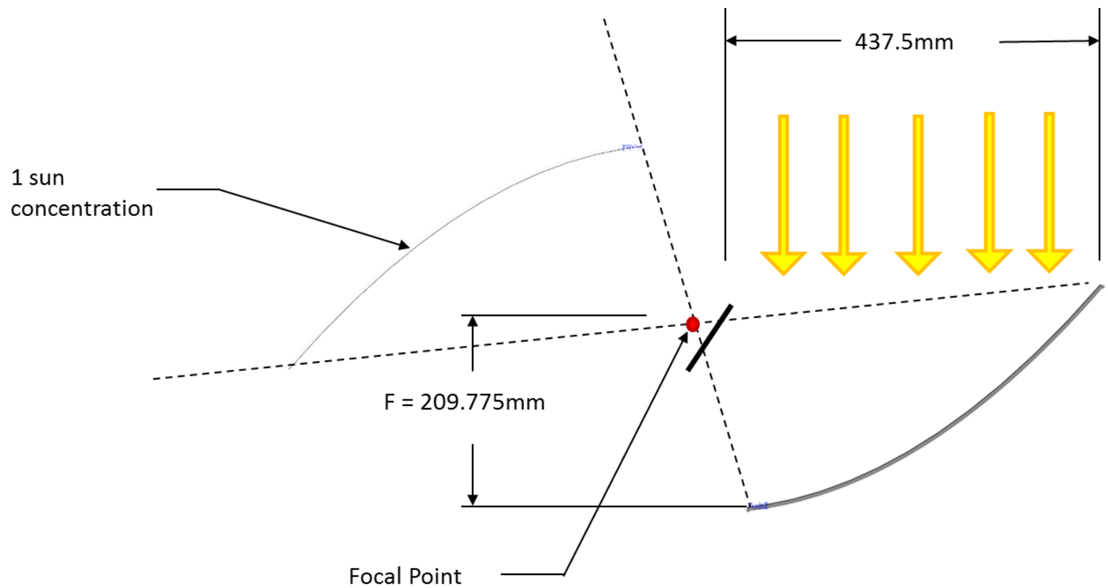


Figure 6: Specular reflection light intensity as a function of distance from the receiver

Beyond d = 0.210m light intensity continues to decrease with distance as shown in Figure 7 below. For example, an observer standing 2 m away will see a light intensity of about 100 W/m^2 assuming a peak intensity of $11kW/m^2$ at the receiver. Additionally, if we compare the values in the graph below to the thresholds of ANSI 2000, the Carrizo study (5) and Brumleve (3) we find that at a distance of 300 mm from the focal point, glint reflection starts to meet the more stringent allowable levels in the worst case scenario.

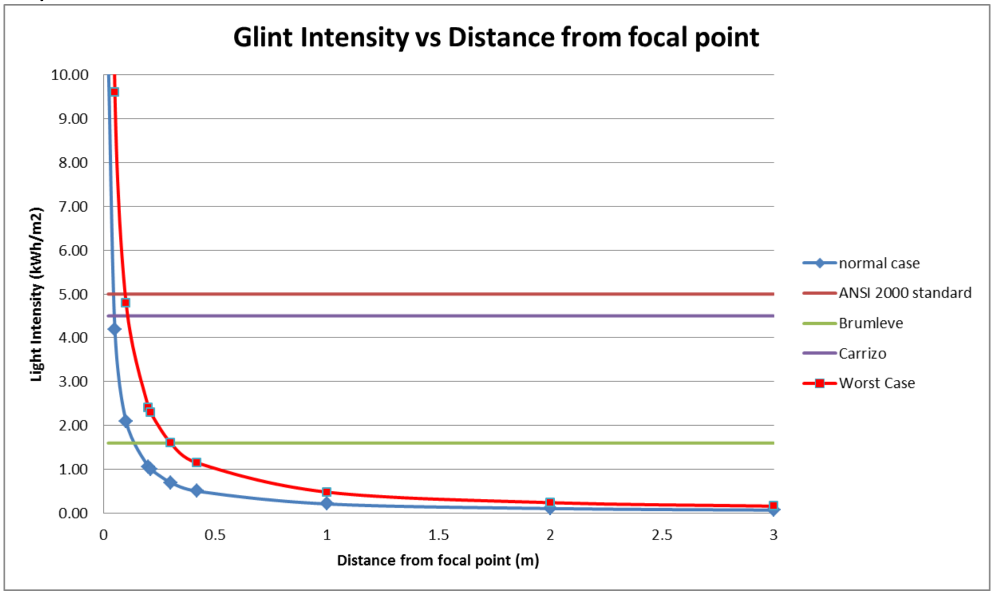
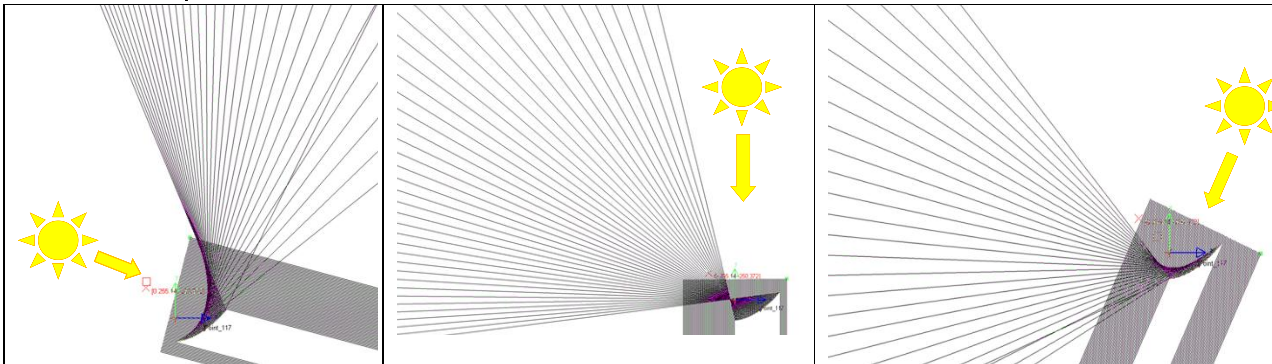


Figure 7: Glint intensity as a function of distance away from the focal point.

We can conclude that ANSI 2000 and Brumleve thresholds are met, in the worst case scenario, at about 0.150m and 0.300 m away from the focal point respectively, making the glint hazard acceptable even for close working distances. An observer standing 2 m away will be subject to a light intensity 10 times less than looking at the sun directly.

When comparing C7 glint levels to other surfaces, conservatively taken at their least reflective state, we can see from Figure 9 below that depending on distance from the local point, the C7 glint level drop below smooth water, solar glass and Anti-Reflection coated solar glass (C1 case). The plot below shows two scenarios for C7 mirrors focal length. The first represented by the blue curve, is the scenario of a mirror placed under normal operating conditions (when the system is tracking), the mirror focal length associated with that is f1 =0.209755 mm (approximately 0.210m). The second scenario, the red curve, represents the longest focal length of the mirror f2 = 0.480m, which is the worst case scenario seen when the reflector is out of its nominal position relative to the sun. In other words, mirrors on a fixed or non-operational tracker will have at most of focal distance of f2= 0.480m as the sun moves relative to the mirror position as described in Figure 8.



Sun at East relative to mirror	Sun normal to mirror (operating condition)	Sun at west of the mirror

Figure 8: Example of light being diffused at different focal lengths depending on the sun position relative to the mirror.

During normal operation, if there is no receiver or other obstacle in front of a mirror, light intensity reflected from the mirror will follow the blue line in the graph below. This indicates that at a distance of about 6 m from the focal point, reflected light will be diffused to intensity levels below that of the sun's reflection on smooth water and solar glass. At a distance of about 9 m away from the focal point light will be diffused below intensity level reflected from AR coated solar glass (which is the case for SunPower flat panels).

During any other condition, the focal length of scenario 2 will be the governing case. In that case, light intensity reflected from mirrors will drop below smooth water and solar glass reflection levels at a distance of about 12 m. Furthermore, at a distance of about 20 m light intensity will drop below reflection levels for AR coated glass.

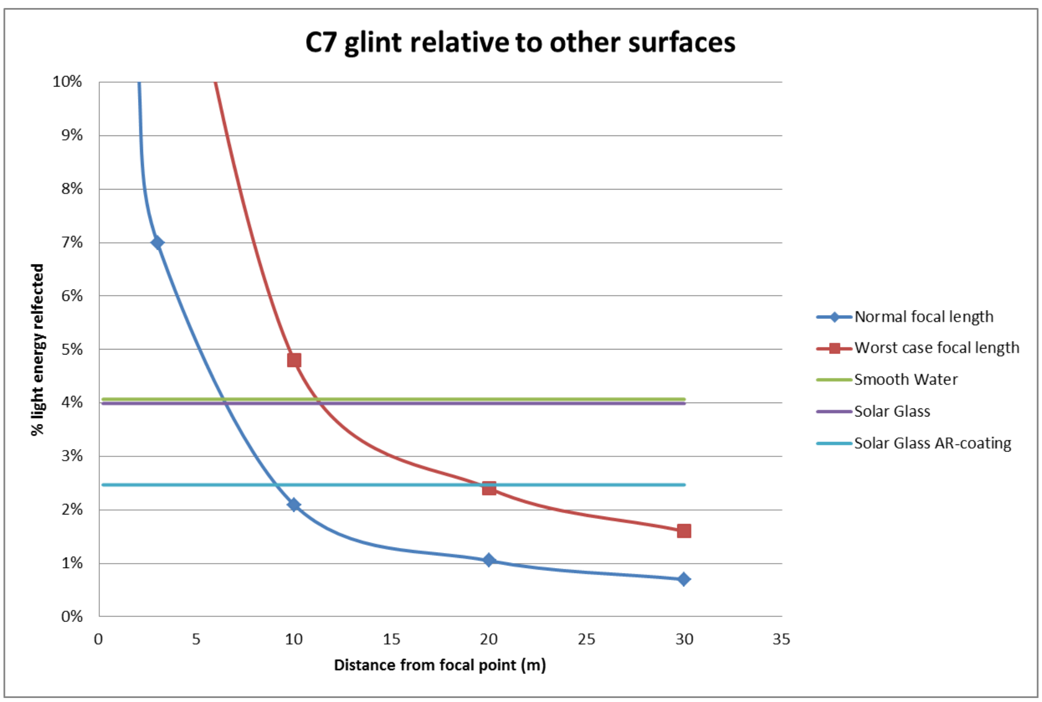


Figure 9: C7 glint level relative to other reflective surfaces

Glare Analysis:

While the C7 tracker has been designed for a geometrical concentration factor of 7x, it can experience optical concentrations of about 11x when light is concentrated from an aperture of 0.4375m onto a target of about 0.040 m. At its peak production a receiver will be subject to about 11 kW/m^2 of light intensity (assuming incident sun light intensity of 1kW/m^2). Glare from the receiver will be reflected in a diffuse manner as shown in Figure 10. If we take the conservative assumption that the receiver glass is not coated with an anti-reflective coating (the receiver is actually AR coated), we can anticipate a light reflection of at most 4% from the front surface of the glass receiver. Additionally, the remainder of light transmitted through the glass is mostly absorbed by the photovoltaic cells (>95% absorptivity from 380 to 1000nm) or transmits through the cell for wavelengths larger than 1000nm. From this information we can estimate the total light reflected from the receiver to be about 9% of the incident light, thus light intensity at the receiver is 0.09*11kW/m^2 = 0.99 kW/m^2 roughly the same intensity from the sun.

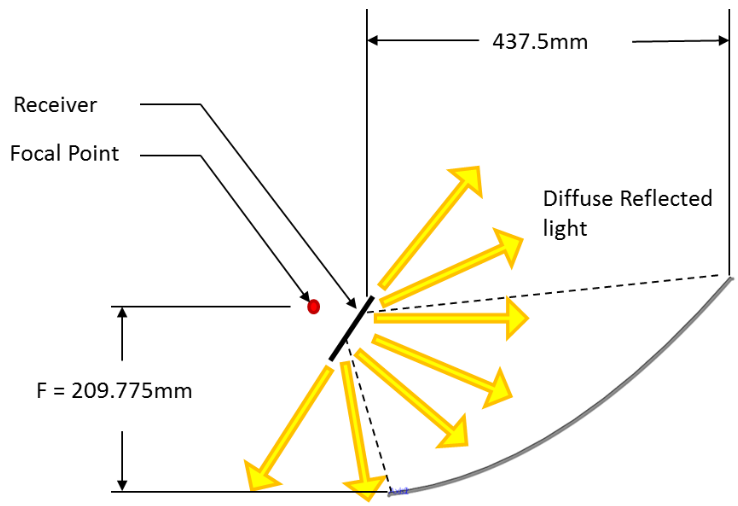


Figure 10: Glare or diffuse light scattering from the receiver.

By approximating the Lambertian scatter as uniform over the half cylinder formed around the receiver (5), one can estimate the intensity of light at the eye of an observer or the corneal irradiance, Ec. The intensity drops off as a function of distance from the receiver per Figure 11. If we take the instance of an observer looking at a 40 mm wide receiver from a distance of about 1m, the ratio of light intensity decrease is 0.04: 3.1415 = 0.01273. The light intensity reflected from the receiver is 0.01273*0.99 = 0.0126 kW/m^2 (about 80 times less than the intensity of the sun). This intensity is also well below the 1.6kW/m^2 safety threshold proposed by Brumleve (4), 4.5 kW/m^2 of the Carrizo study (5) or the 5kW/m^2 safety threshold proposed by ANSI 2000 standard (1).

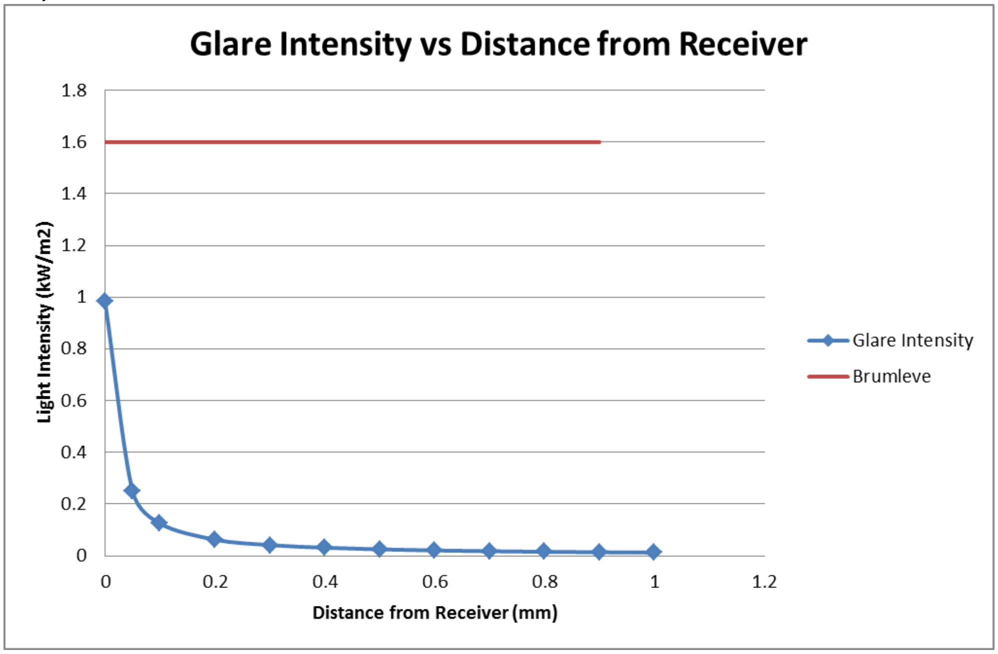


Figure 11: Glare intensity as a function of distance from the receiver

Figure 11 above indicates that at the receiver glare levels are below the ANSI 2000 standard, the Carrizo study and Brumleve's safety thresholds for the human eye discussed above.

Further comparing glare values to other surfaces as seen in Figure 12, we can conclude that C7 glare light intensity from the receivers is below the level of light intensity reflect from smooth water or Solar Glass starting at a distance of about 0.3m. Starting at about 0.55m C7 glare from the receiver is below light intensity from reflection on AR coated glass (case of SunPower flat panels)

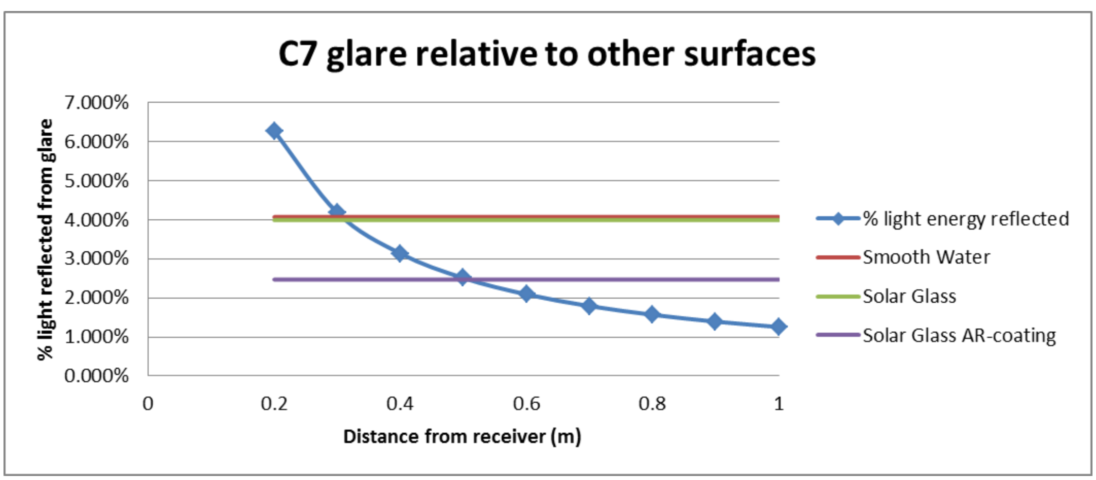


Figure 12: C7 Glare values relative to other surfaces. At 0.3 m away from the receiver glare levels of smooth water and solar glass are reached. Beyond 0.55m C7 glare levels a less than AR coated solar glass.

Cases to Consider:

Reflectors moving from stow position to tracking position:

Another condition of concern would be when the tracker is moving from stow position to tracking position. In this case the light reflected off the mirrors might be reflected off-axis and result in light spillage. In these conditions the light spillage will not exceed the worst case considered in the glint analysis. In addition, given the chosen configuration of receivers and mirrors, light spillage will be captured to a large extent by an oversized receiver and the back of the mirror to which the receiver is mounted. This affords further protection from glare and glint.

Tracking system malfunction or failure:

In the case of system failure, light incident of the reflectors off-axis will be reflected with the glint analysis being the worst case scenario.

Washing:

During cleaning activities trackers are rotated to face each other off-sun. During their rotation mirrors reflection will be subject to the same worst case scenario as described above.

Conclusion:

Glint and glare from concentrated solar technology has been shown in many instances to not exceed the safe level for the human eye. The SunPower C7 reflector, by virtue of its short focal length has been shown to cause glint level much lower than allowable thresholds. The glare levels from the C7 system are very low as well primarily due to the low concentration ratio (7x to 11x) of the system and the high absorptivity of SunPower cells. One can conclude from the glare and glint analysis above that the above mentioned distances, the C7 tracker will not cause glint and glare levels above allowable limits.

Compared to SunPower flat panels, AR coated, used in the C1 product, the following statements can be concluded from the analysis:

1) Glint level for C7 (direct reflection from mirrors) during worst case scenario will be below glint from smooth water and solar glass for distances greater than approximately 12 m away from the system and will be below SunPower AR coated flat panels (C1) for distances greater than approximately 20 m.
2) Glare level (diffuse reflection from the receiver) will be below SunPower flat panel AR coated (C1) for distances greater than approx. 0.55m from the receiver

Compared to typical safety metrics used in assessing glint and glare hazard in concentrated solar systems, the C7 glint and glare levels are below the thresholds and therefore considered safe at distances larger than 0.300m from the focal zone.

Finally, the receivers are coated with anti-reflection coatings further minimizing glare from receiver as per mitigation measure MM4.1-6LA.

Works Cited

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