# Simulation of a Compact Large-Area Radiometric Light Source

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## Abstract

The performance of a novel compact large-area radiometric light source (CLARLS) has recently been demonstrated by the SeaWiFS ( Sea-viewing Wide Field-of-View Sensor) Quality Monitor built for the SeaWiFS Calibration and Validation Program. The SeaWiFS Quality Monitor (SQM) was successfully used as a calibration source onboard two trans-Atlantic cruises. The success of the CLARLS relies mostly on the uniformity of optical radiance it provides for sensor calibration. A theory to model the uniformity must account for the light scattering inside its light chamber. Here, such a model is proposed and the results of the numerical simulation are discussed.

Keywords: radiometric source, large-area light source, SeaWiFS, light source simulation

## 1. Introduction

Recently, a novel compact large-area radiometric light source (CLARLS) was developed[1] and was used to construct a portable on-board calibration light source for marine radiometers in response to the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Calibration and Validation Program[2,3] by National Aeronautics and Space Administration's Goddard Space Flight Center. The engineering model of this device, the SeaWiFS Quality Monitor (SQM), was used onboard two trans-Atlantic cruises to quantify the changes in efficiency of the radiometers that were used for collecting ocean-color data. The SQM has a radiance variation less than 4% over an area of 15cm in diameter. Excellent stability and resistance to environmental changes enable the monitoring of marine-radiometer efficiency changes down to less than 1% level for the entire cruise. Details of the structure of SQM and its laboratory and field performance were described in Ref. 4 and 5. Given the success of SQM, the CLARLS holds a great potential for becoming a new class of radiometric light source. With its simple structure and compact size, the CLARLS can be used as an alternative to the much more bulky and expensive integrating spheres and the high uncertainty of a plaque when used in conjunction with a standard irradiance lamp for large field-of-view radiance calibration.

The basic design of the CLARLS is shown in Fig. 1. A number of quartz-halogen miniature lamps are arranged symmetrically on the circumference of a circle. All the lamps are enclosed in a cylinder with the plane of the lamps facing one side of the cylinder where a thin plastic diffuser is mounted. The diffuser serves as the exit port for the uniform and diffused light. The inner surfaces of the other side of the cylinder and the cylindrical wall are diffuse reflectors. Typical surfaces are bead-blasted aluminum.

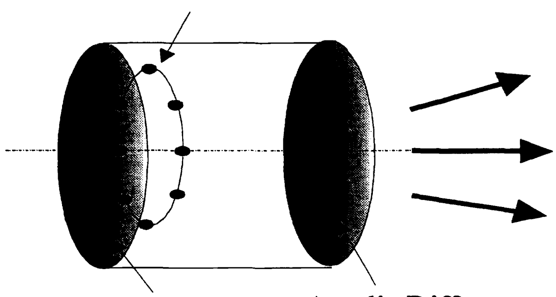


**Figure 1.** Schematic of the CLARLS

An important parameter of the CLARLS that determines the uniformity of the light from the diffuser is the *r/d* value, where *d* is the distance between the plane of the lamps and the diffuser and *r* is the radius of the circle that the lamps are positioned. The spatial homogeneity of the output light can be optimized by a proper choice of the *r/d* value.

To understand this effect, a very simplified simulation was described in Ref. 4. This simulation calculates the total irradiance on any point on the diffuser from the direct irradiation of each individual lamp. The variation of irradiance across the diffuser can then be simulated as a function of the *r/d* value. The results of this calculation show qualitative agreement with the measured spatial homogeneity. A similar calculation will be discussed in section 3.

Despite the fact that the simulation described above qualitatively agrees with measurement, it ignores light inside the chamber that undergoes multiple reflections from the walls before exiting from the diffuser. Results from the simulation of this paper show that as much as 85% of the output light undergoes at least one reflection from the walls of the cylinder. To better understand and predict the behavior of the CLARLS, an improved model that includes multiple reflections is clearly required. Such a model is discussed below.

## 2. A New Model for the CLARLS

To simplify the simulation and shorten the computation time, two assumptions are made for the new model to calculate the radiance homogeneity of the CLARLS. (1) Instead of discrete lamps, the light source inside the CLARLS is a uniform line source in the shape of a circle. (2) The inner surfaces of all the walls of the cylinder diffuse light as perfect Lambertian diffusers. Assumption (1) provides axial symmetry for the model and greatly reduces the amount of finite elements used for computation. For a typical system like the SQM where there are 8 to 16 lamps, a ring source is a good approximation as long as the plane of the lamps is not too close to the diffuser. Such a condition introduces large spatial variation in radiance for CLARLS and is not useful as a radiometric light source.

The computer program used to simulate CLARLS is written in Basic language. Typical running time for each set of input parameters on a 200 MHz desktop computer is only about 20 minutes. The input parameters for this program are:

Radius of the circular light source: $\boldsymbol{r}$
Radius of the cylinder: $\boldsymbol{R}$
Distance from the plane of the light source to the diffuser: $\boldsymbol{d}$
Distance from the plane of the light source to the lamp plate: $\boldsymbol{d'}$
Total reflectance of the walls of the cylinder: $\boldsymbol{R_{cw}}$
Total reflectance of the diffuser: $\boldsymbol{R_{diff}}$
Total transmittance of the diffuser: $\boldsymbol{T_{diff}}$

## 3. Simulation of Direct Irradiation

The first step of the numerical simulation is to calculate the direct light irradiation from the light source to the inner surfaces of the entire cylinder. In this case, the irradiance at a point on the diffuser can be derived as

$$I_{diff}(s) = \frac{1}{8\pi^2} \int_0^{2\pi} \frac{d}{(r^2 + d^2 + s^2 - 2rs\cos\phi)^{\frac{3}{2}}} d\phi \qquad (1)$$

where *s* is the distance from the point of interest to the center of the diffuser. Note that the denominator of the integral in the above expression is the distance between the point where the irradiance is to be calculated and a point of the light source to the third power. The above expression is the same as the simulation equation used in Ref. 4 when the continuous integration is replaced by the discrete summation over the individual lamps.

Similar expressions to equation (1) can be derived to calculate the values of irradiance on both the cylindrical wall and the end plate of the cylinder opposite to the diffuser. Based on these equations, the program calculates the irradiance values for the entire surface of the cylinder and stores these values in an array to prepare for the multiple reflection calculation.

## 4. Simulation of Multiple Reflections

Light reflection processes inside a cylinder can be reduced to four reflection types depend on the position of the reflector and where the reflected light is irradiating. The four types are light diffusely scattered from (1) the cylindrical wall to the end plates (2) one end plate to the other (3) one end plate to the cylindrical wall and (4) cylindrical wall to cylindrical wall. Due to axial symmetry, this simulation uses a thin ring on the cylindrical wall or on the end plates as a reflector for each finite-element calculation. With this method, the first two cases of reflection processes are illustrated in Figure 2 where two thin rings, one on the cylindrical wall and one on the end plate, are to reflect light to a point S on the remaining end plate. The resulted irradiance at point S for the two cases in Figure 2 can be derived as

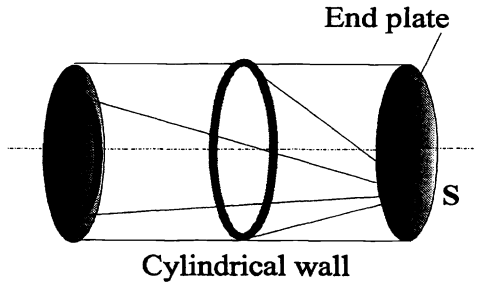


**Figure 2.** Light reflection from two rings, one on the cylindrical wall and the other on the end plate, to a point S on the end plate.

$$I_{dw}(s,d_0) = \frac{d_0}{2\pi^2}\int_0^{2\pi}\frac{r - s\cos\phi}{(r^2 + d_0^2 + s^2 - 2rs\cos\phi)^2}d\phi \tag{2}$$

and

$$I_{de}(s,r_0) = \frac{1}{2\pi^2}\int_0^{2\pi}\frac{d^2}{(r_0^2 + d^2 + s^2 - 2rs\cos\phi)^2}d\phi \tag{3}$$

where $s$ is the distance from the center axis of the cylinder to point S, and $d$ is the distance between the plane of the end plate that contains point S to the plane defined by the thin ring diffuse reflector. Note that the denominators of the integral in the above expressions are the distance between point S and a point on the ring of the reflector to the fourth power compared with the third power for direct irradiation from a uniform light source. This is due to the cosine law for Lambertian diffusers in contrast to isotropic light emission.

Similar expressions to the above two equations can also be derived for the other two cases of light reflections. The simulation calculates all these integrals and sums over the entire cylinder to get the irradiance on every point of the cylinder.

## 5. Results and Discussion

A numerical simulation of the CLARLS spatial homogeneity was performed based on the following realistic set of parameters:

Radius of the circular light source: $\boldsymbol{r} = 1$
Radius of the cylinder: $\boldsymbol{R} = 1.1$
Distance from the plane of the light source to the lamp plate: $\boldsymbol{d'} = 0.1$
Total reflectance of the walls of the cylinder: $\boldsymbol{R_{cw}} = 0.8$
Total reflectance of the diffuser: $\boldsymbol{R_{diff}} = 0.2$

Total transmittance of the diffuser: $T_{diff} = 0.2$

The selection of the value 0.8 for $R_{cw}$ is in accord with a normal metal surface rather than a high-reflectivity coating. The parameters for the diffuser also include a significant amount of light being absorbed by the diffuser. With the above parameters fixed, the simulation program performs a series of calculations for different values of $d/r$. For each value of $d/r$, the program first calculates the direct irradiation from the light source to the entire cylinder and then performs the calculation for the reflection of light. The program traces light inside the cylinder to 10 reflections that accounts for more than 99.8% of the total amount of light from the diffuser. Figures 3, 4, and 5 show the results of the simulation for $d/r$=1.2, 0.8, and 1.0, respectively. For the largest $d/r$ value of 1.2, figure 3 shows a broad peak centered at $r$=0 for all the curves. For the smallest $d/r$ value of 0.8, figure 4 shows the center peak drifts away and develops a valley at $r$=0. Between these two conditions, figure 5 shows a flat region near $r$=0 with $d/r$=1.0. Note that these figures indicate the contribution of the output light from direct irradiation is less than 15% of the total output light. This result clearly shows the importance of multiple reflections.

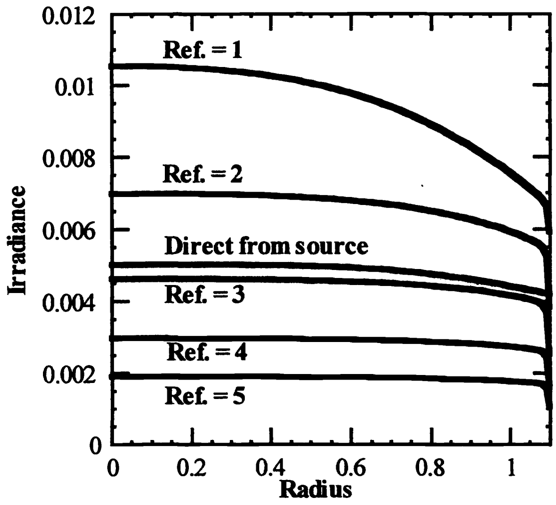


**Figure 3.** Simulation of transmitted light from the diffuser by direct irradiation from the light source and by light that undergoes up to five reflections for $d/r$=1.2.

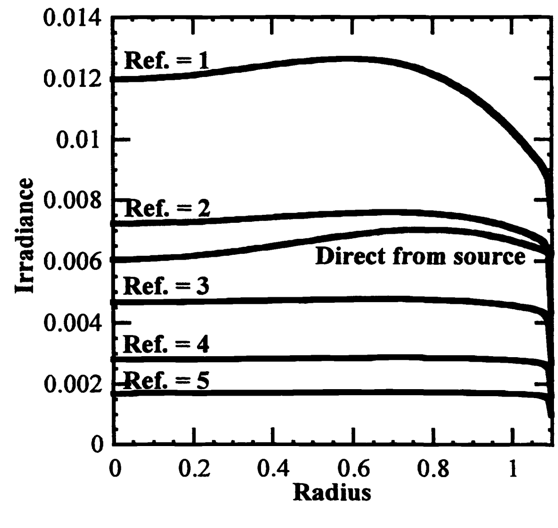


**Figure 4.** Simulation of transmitted light from the diffuser by direct irradiation from the light source and by light that undergoes up to five reflections for $d/r$=0.8.

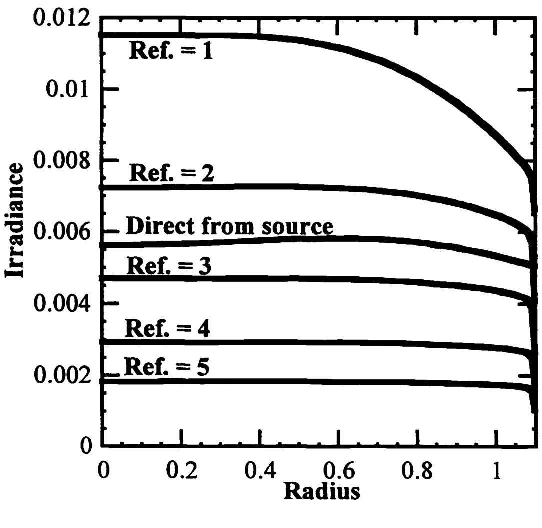


**Figure 5.** Simulation of transmitted light from the diffuser by direct irradiation from the light source and by light that undergoes up to five reflections for $d/r$=1.0.

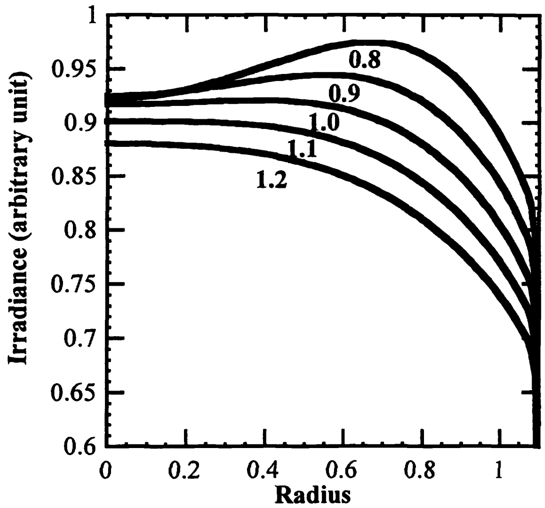


**Figure 6.** Calculated uniformity of CLARLS up to 10 reflections for *d/r*=0.8, 0.9, 1.0, 1.1, and 1.2.

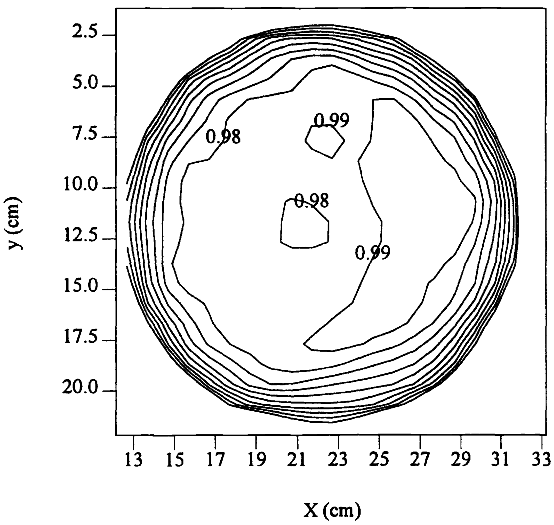


**Figure 7.** Contour plot of measured homogeneity of a laboratory CLARLS with *d/r*=0.94. Each contour line is in 1% step.

Figure 6 shows the total light output by summing all the light that undergo less than 10 reflections inside the cylinder. For *d/r*=1.0 and 0.9, there is less than 2% variation within an area with a radius of 0.7.

The above simulation was compared with measurements from a laboratory CLARLS. The CLARLS was constructed with a cylinder of 11.5 cm in radius. Eight miniature lamps were positioned around a circle with *r*=10.8 cm. The distance *d* between the lamp ring and the acrylic diffuser is 10.2 cm. This gives a value of 0.94 for *d/r*. The homogeneity was measured by scanning a photodiode across the diffuser. Apertures of the photodiode limited the viewing area of the diffuser on the photodiode to about 1 cm in diameter. The results are shown in figure 7. It can be seen that less than 2% variation was achieved in an area of 14 cm in diameter as predicted by this simulation.

## 6. Conclusion

A model that includes the multiple reflections inside CLARLS was used to simulate the spatial homogeneity of output light from CLARLS. The simulation calculates the contribution to the output light from light inside the cylinder of the CLARLS that undergoes a fixed number of reflections. The spatial homogeneity was subsequently calculated by summing the contributions from all numbers of reflections. Numerical simulation showed that, in accord with actual measurements, a large-area of homogeneous light output can be achieved by proper choice of the distance from the lamp ring to the output diffuser.


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