Constructing multiple focal points using rayfiles

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ABSTRACT
Many methods for non-imaging optical design and analysis use a simple point model with an assigned light intensity distribution as the source of an optical system. Finding the best position in space to place this virtual source is difficult, especially if the system includes beam shaping primary optical elements. Furthermore, using one point source is simply not accurate enough for some applications.
This contribution proposes a new method that creates optimized point source based models utilizing rayfiles and the concept of multiple Ray Focal Points. These models can then be used to analyze optical systems or to perform optical design of secondary elements by methods like 2D-Tailoring. Several applications for this approach are shown, the results are presented as simulated light distributions.

Keywords: *Optical Design, Rayfiles, Light Source Modeling, Ray Focal Points*

1 INTRODUCTION

The primary task of non-imaging optical design is collecting the light output of a given source and redirecting it in such a way, that a specific illumination task is fulfilled. There are numerous methods to calculate and optimize optical surfaces, that use refraction, reflection or scattering to achieve a desired light distribution.
A crucial ingredient of the optical design and analysis process is the light source model. Depending on the type of illumination task, the dimensions and distances and many other boundary conditions, a suitable source model needs to be chosen. In any case, a trade-off between several features of the model has to be made, primarily between accuracy, complexity and availability. Typically, a very accurate model including all optical and geometrical informations in detail [1] is hard to get and also difficult to handle. On the other hand, a very simple model like a point source with an assigned light intensity distribution renders the design process relatively easy but neglects important source properties, that can spoil the results.
Therefore the main purpose of this contribution is the detailed presentation of a new method generating problem specific light source models that combine the advantages of simple point sources with complex spatial and angular near field source informations.
A graphical representation of this concept is shown in fig.1. The figure shows examples for "ideal" source models with regard to accuracy, handling and availability attributes. State-of-the-art models including these attributes to different amounts are rayfiles in which accuracy is

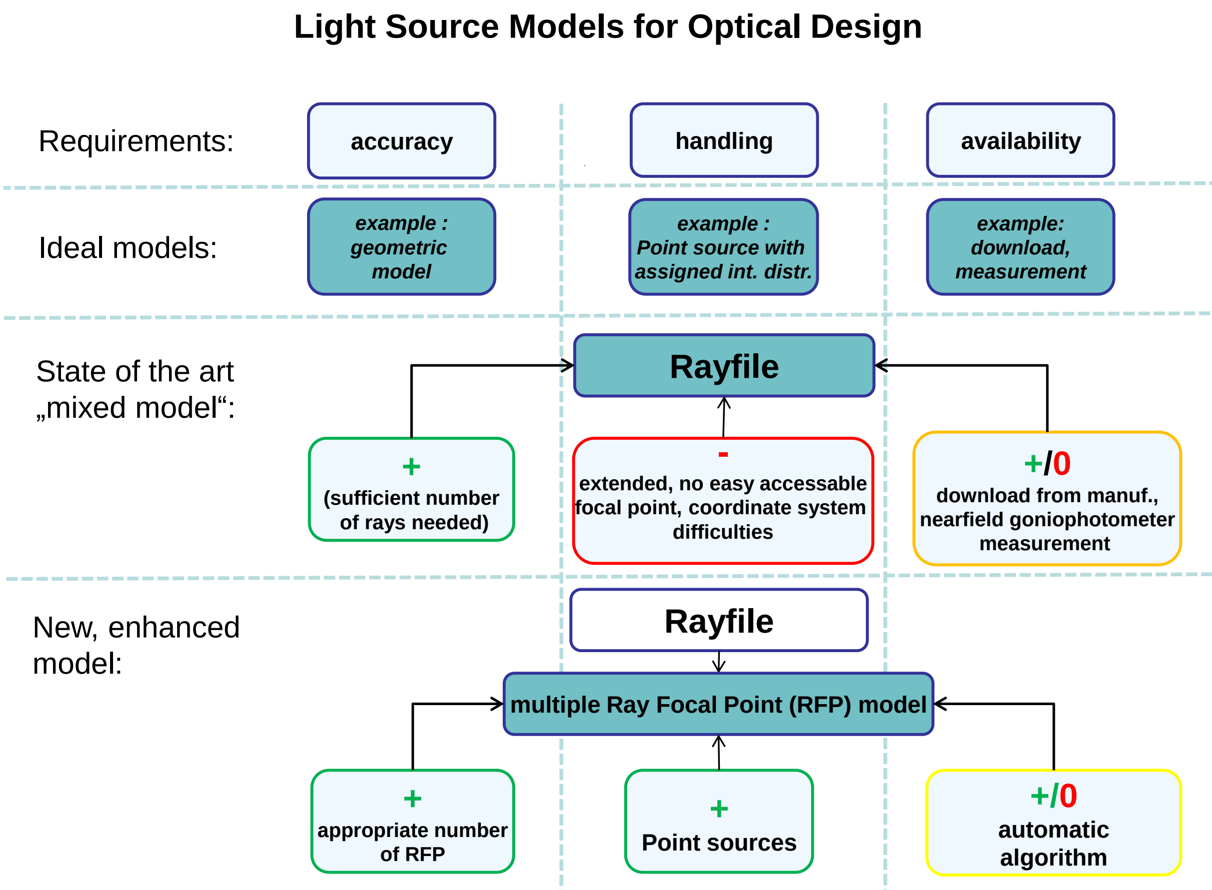


Figure 1: Light source models for optical design

the most important property. Rayfiles are available via manufacturer download or nearfield-goniophotometer measurements. Their main disadvantage from an optic designers point of view is their complexity considering the spatial and angular extension and the lack of a focal point.

With the methods proposed in this contribution, a given rayfile can be analyzed and depending on the chosen parameters, a global or multiple Ray Focal Point(RFP) model can be calculated. Using this model enables many important optical design methods relying on point sources like Cartesian Ovals [2], employment of spherical/elliptical surfaces or tailoring algorithms [3][4]. The calculational procedure for RFPs are covered in chap.2 whereas chap.3 features some application examples including simulated illuminance and intensity distributions for secondary optical designs created with RFP source models. Finally, chap.4 gives a conclusion.

2 RAY FOCAL POINTS

In this section, the concept of Ray Focal Points (RFP) is presented.
The RFPs are based on rayfiles and therefore the important properties of rayfiles are explained in sec.2.1. The mathematical and geometrical principals of RFPs using a minimized figure of merit are then given in sec.2.2. As sec.2.3 demonstrates, creating a multiple RFP model can increase the accuracy and field of application further.

2.1 Rayfiles

Rayfiles are a specific kind of data containing angular and spatial luminance information about the radiation pattern of an extended light source [5]. The main component of all kinds of rayfiles is a typically long list of rays. Each ray is defined by a starting point in 3D space (X,Y,Z), a Cartesian 3D direction vector (A,B,C) and a numerical value (F) describing the amount of flux carried by the ray. An exemplary illustration for an ASAP-type rayfile is shown in fig.2.
In this way, the rayfile is kind of a pointwise sampled description of the real, continuous luminance distribution $L = L(surface, direction)[\frac{lm}{m^2 \cdot sr}]$ of the light source. To get a statistically sufficient sample, typical ray numbers are 10^5 to $5 \cdot 10^6$.

```
Record1: ASAP-Strahlenfile mit 4 * 7 = 28 Bytes je Record
Record2: "BULB_DUMPRAYSET         " 7
Record3: "Tot FLUX          "      47.226257 "XYZABCF MM       "
Record4: "Ray Number        "       1.000000      99924.000000  -99923
Record5: "Wavelength        "       0.000000          0.000000  -1
Record6 und folgende:
 X          Y          Z         | A          B          C         | F
 4.350e+00 -6.704e+00 -3.503e-01 | 8.834e-01  3.073e-02  4.676e-01 | 1.509e-09
 4.273e+00 -6.755e+00 -3.413e-01 | 8.827e-01  2.063e-02  4.694e-01 | 1.509e-09
 7.997e+00 -2.051e-01 -6.221e-02 | 9.656e-01  3.997e-03  2.600e-01 | 7.464e-05
 7.997e+00  1.529e-01  1.309e-01 | 9.634e-01  5.175e-03  2.682e-01 | 7.464e-05
 7.994e+00  2.013e-01  2.507e-01 | 9.639e-01  3.154e-03  2.662e-01 | 7.464e-05
 7.997e+00 -2.139e-01  5.553e-03 | 9.678e-01  3.723e-03  2.516e-01 | 2.731e-04
 7.999e+00 -2.092e-03  1.464e-01 | 9.685e-01  5.720e-03  2.489e-01 | 2.731e-04
 7.990e+00  3.197e-01 -2.470e-01 | 9.719e-01 -3.219e-03  2.354e-01 | 3.158e-04
        starting point                      direction                 flux
```

Figure 2: ASAP rayfile example showing the header and the first 8 of 99924 rays

For LEDs without primary optics, access to rayfiles is often provided directly through manufacturers via download. More complex systems including primary optical elements require near-field goniophotometer measurements [6] and subsequent software conversion. A perspective view of a rayfile of a LED with a side emitting primary optic is given in fig.3.

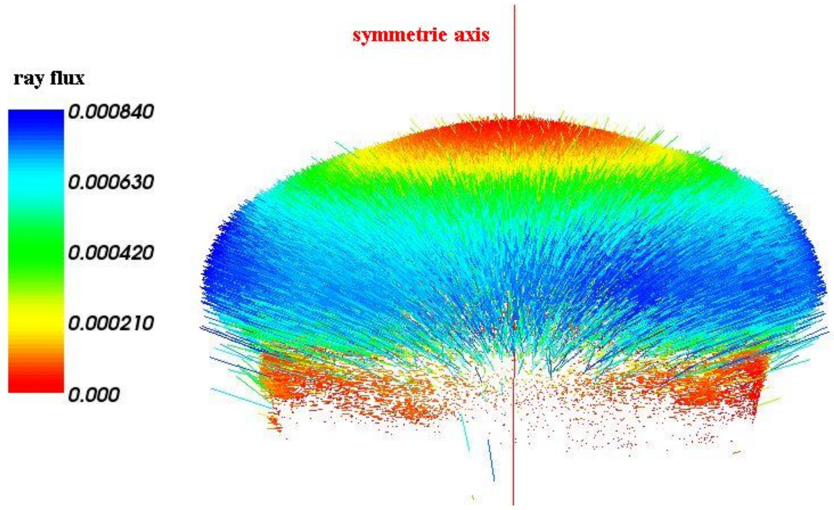


Figure 3: Visualization for a rayfile of a measured side emitting LED. The ray starting points are projected on a sphere enclosing the LED, the color indicates the ray intensity.

2.2 RFP and Figure of Merit

The easiest state-of-the-art way to perform the source model transformation from rayfiles to point sources is getting the intensity distribution $I = I(\theta, \phi)$ $[cd]$ by spatial integration via calculation or simulation (symbolic: $I(\theta, \phi) = \int_{surface} L(surface, \theta, \phi)$) and assigning it to the "supposed" LEDs central position. In the case of downloaded rayfiles, this is often the rayfile origin or it can by calculated via provided geometrical information. If near field measurements are used, there is an additional uncertainty of the LED position with respect to the goniometer center of rotation, especially if LEDs with primary optics are used.
In any case, the rayfile origin is usually not optimized to get the most accurate point source model for the light source. If we consider a LED with a beam spreading primary optic, a much better point source position than the die position is somewhere closer to the exit surface. A symbolic view for this example is shown in fig.4. In a more general manner, the basic idea of RFPs is calculating a specific and mathematical unique position in space, that is best suited to represent the radiation behavior of a given light source.

RayAnalyzer
All calculations presented in the following sections were implemented in a software toolbox called RayAnalyzer , which includes a graphical user interface, several options to load and save rayfiles, perform specific analysis and create scalable and rotatable 3D views.

In order to do create RFPS, our general approach is to define a **figure of merit** $Q = Q(S(x, y, z))$ that assigns a numerical value to every point in space $S(x, y, z)$, measuring the quality of S as the RFP of the rayfile. Furthermore, $Q(S)$ needs to be continuous and positive definite with a unique minimum Q_{min} which then corresponds to S_{min} as the final RFP with the highest quality.

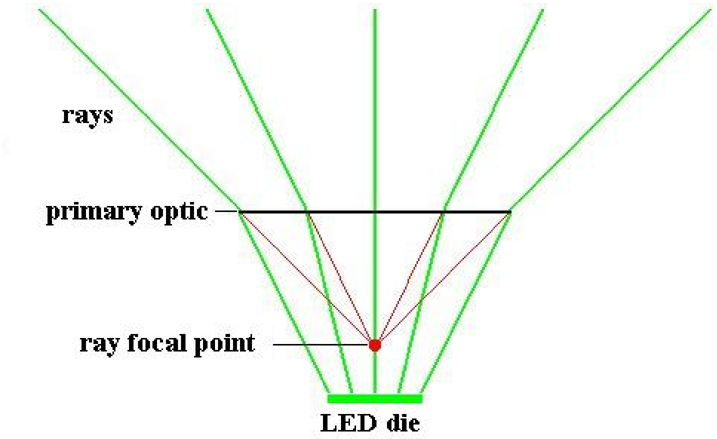


Figure 4: Principle of a RFP for a beam spreading primary optic

Plane Intersection Method

We investigated different definitions for Q, based on analogies to similar modeling tasks in physics. For example, a spatial distribution of masses $m = m(x, y, z)$ is often modeled by a center of mass R, that is calculated by the sum of distances $\mathbf{r(S)}$ weighted with their respective mass $m(\mathbf{r})$ as shown in eqn.1. Also the integrated mass m_{total} is assigned to R.

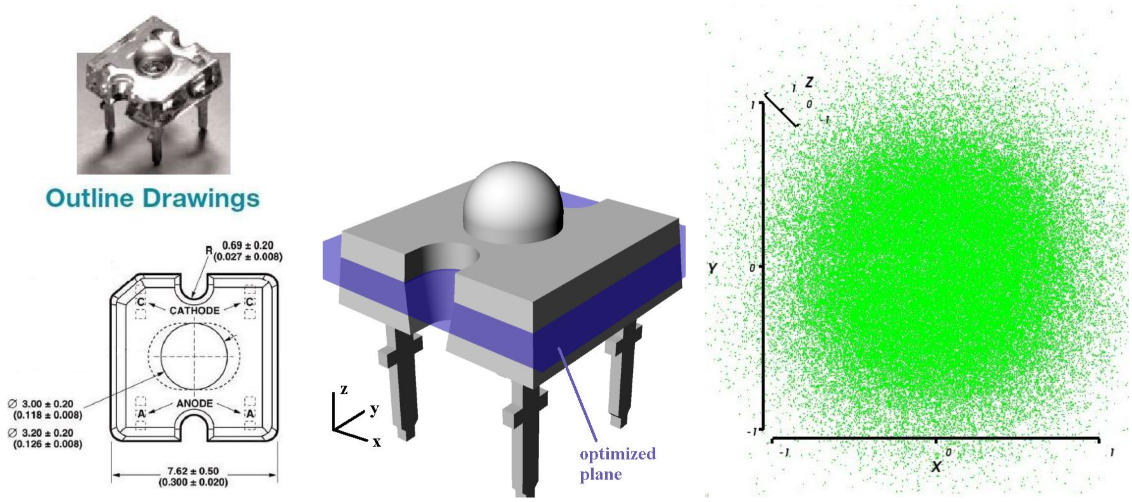
$$R = \int_V m(\mathbf{r}) \cdot \mathbf{r} \quad dV \tag{1}$$

This principle can also be applied to rayfiles in a modified version. The mass m_{total} corresponds to the total far field intensity distribution $I(\theta, \phi)$ of the source. To get the RFP position, a plane perpendicular to the main beam direction of the rayfile is defined and all intersection points P_{sec} of the n rays with this plane can be calculated easily. In this way, a center of mass like position in this plane can be calculated with eqn.1 if the integral is replaced by a sum and the ray fluxes Φ_i are plugged in for the masses m leading to eqn.2. The resulting point S represents the RFP of this plane and is assigned to a value Q_S via. eqn.3, fulfilling the figure of merit requirements mentioned above.

$$S = \sum_n \Phi_i \cdot P_{sec,i} \tag{2}$$

$$Q(S) = \sum_n \Phi_i^2 \cdot (P_{sec,i} - S)^2 \tag{3}$$

Shifting the plane along the optical axis (w.l.o.g. the z-axis) changes Q and therefore results in an analytic expression for $Q = Q(z)$, which turns out to be a polynomial of degree two. Using its derivative $\frac{dQ(z)}{dz}$, the RFP with the minimal Q_{min} value located in the optimized plane at z_{opt} can be obtained. As an example, the downloaded rayfile of a SuperFlux HPWT Dxxx LED (50° viewing angle) [8] with a collimating primary lens was analyzed and the optimized RFP was calculated. The results are presented in fig.5. The RFP coordinates with respect to the rayfile origin are $x = 0, y = 0, z = -0.84$ [mm] which means the RFP is located behind the die position as expected for a collimating lens and in good agreement with the "focal smear" description for SuperFlux LEDs in [9]. The value of the figure of merit Q for this RFP is less than half of the value for the rayfile origin implying a much better point source description.



(a) SuperFlux photo and dimensions (b) Position of the optimized plane (c) Ray intersection points on optimized plane, displayed axis length: 2mm

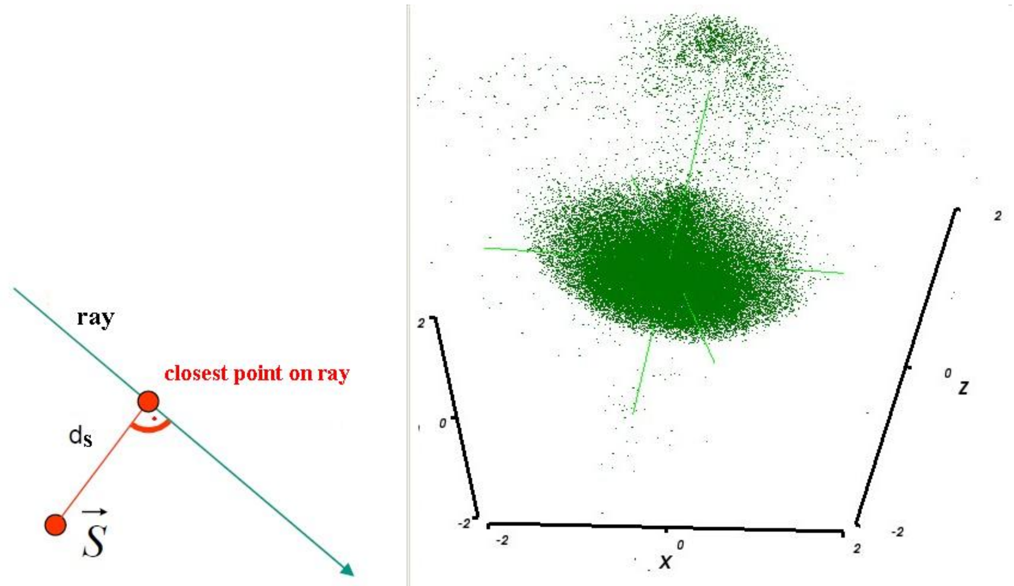
Figure 5: Plane Intersection RFP for a Philips Lumileds SuperFlux HPWT Dxxx LED rayfile [8]

Unfortunately, the Plane Intersection approach struggles with some instabilities and numerical problems especially if high emission angles relative to the optical axis or high amounts of stray light are included. Also, defining the optical axis and the intersection plane orientation can cause problems depending on the luminaire.

Free Space Method

An enhanced approach for the definition of Q relies on a free space distance calculation: Considering an arbitrary point S in 3D space, its distance $d_{P,3D}$ to a straight line like the rays in a rayfile can be obtained by using standard vector analysis methods (cf. fig.6(a)). If eqn.3 is used with this modified 3D-distance, the resulting figure of merit $Q(S)$ gets more complicated compared to the Plane Intersection Method but also, the plane orientation related problems vanish. Minimizing Q becomes much more elaborate due to the fact that the three derivatives $\frac{dQ(S)}{ds_x}, \frac{dQ(S)}{ds_y}, \frac{dQ(S)}{ds_z}$ have to be taken into account. The detailed mathematical expressions are very extensive, therefore they are not presented explicitly in this contribution.
Nevertheless, analytical calculations are possible and the resulting RFP corresponding to the minimal $Q(S)$ turns out to be a very good and mathematically stable description for the analyzed rayfile. An example for the resulting point cloud of the closest position on every ray to the Free Space RFP for the SuperFlux LED from above is displayed in fig.6(b). The accumulation at about $z = 2$ in fig.6(b) corresponds to light with high redirection angles at the front end of the primary optic.

Summing up, with the methods described in this section, a global RFP source model can be constructed for a given rayfile. This model consists of an optimized position in space, that is



(a) Distance between S and a ray in 3D space

(b) 3D-point cloud calculated with Free Space method. The origin of the rayfile is shifted to the RFP (center of the green axis coordinate system).

Figure 6: Free Space Method

best suited to represent the radiation behavior, and an assigned intensity distribution $I(\theta, \phi)$. In general, the more compact a point cloud assigned to the RFP S of a rayfile calculated either using the Plane Intersection or the Free Space method is, the better the point source model will be.

2.3 Multiple RFP model

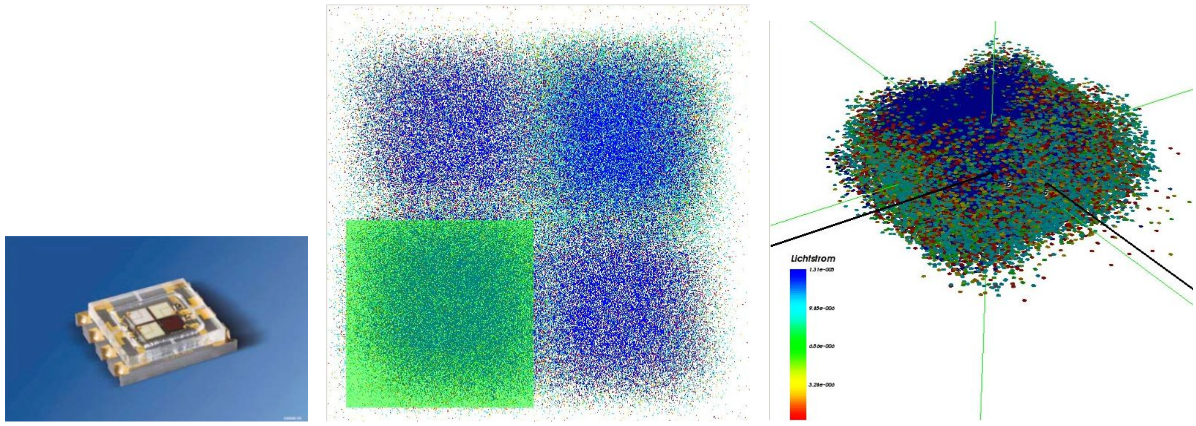
For compact and simple light sources without beam shaping primary optics, the global RFP method described in sec.2.2 is sufficient to obtain a reasonable point source model. In these cases, the RFP usually turns out to be located in the center of a compact point cloud close to the LED die position or centered in the filament. But if optical analysis and design are performed close to a more complicated light source, a model consisting of multiple RFPs can be much more useful.

To create such a model, an important and typically not straight forward choice has to be made to define a **selection criterion**. This criterion decides how many RFPs are calculated and what rays contribute to which RFP. Depending on the type of light source, its radiation behavior and the purpose of the multiple RFP model (simulation, design, analysis), different criteria are suitable. In any case, the main rayfile is decomposed in a list of partial ray files assigned to different RFPs. The most important selection criteria are based on:

- **Spatial Division - Plane Intersection:** Using the global Plane Intersection RFP method allows the selection of specific 2D-regions in the optimized plane. This criterion is useful if the most important features of the light source are primarily located in a planar area. An example for a four-die OSRAM RGB LED [10] is shown in fig.7.

- **Spatial Division - Free Space:** Creating a point cloud with the Global Free Space RFP method enables the possibility to define different regions in 3D space as a separation criterion. This approach can help to analyze 3D extended optics with different redirection mechanisms appearing as distinct point clouds. Fig. 8 displays one simple choice for the SuperFlux LED introduced in sec.2.2.

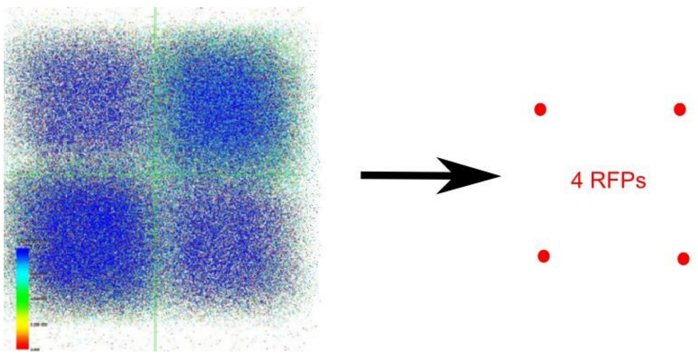
- **Secondary Optic Segmentation:** If the primary optic includes different surfaces and/or ray seperation/crossing-mechanics and a secondary optical element needs to be designed, a suitable segmentation of the secondary optic serves best as the separation criterion. In this case, the intersection points of the rayfile with a number of segments of the approximated shape of the secondary optical surface are calculated. Partial rayfiles related to the rays hitting each specific segment can then be constructed and used to calculate an unique RFP for this segment with the Free Space Method. The great advantage of this separation criterion is the fact, that each segment of the secondary optic is illuminated only by one point source and therefore methods like optical Tailoring can be used to design each segment in detail. A schematic view of the Secondary Optic Segmentation approach for two segments is shown in fig.9.



(a) OSRAM OSTAR SMT LE B S2W

(b) Intersec. points on RFP-optimized Plane at $z = 0.93$ with selected rectangular region

(c) Point cloud for Free Space RFP of partial rayfile of selected region



(d) 4 Free Space RFP model

Figure 7: Selection criterion: Spatial Division - Plane Intersection

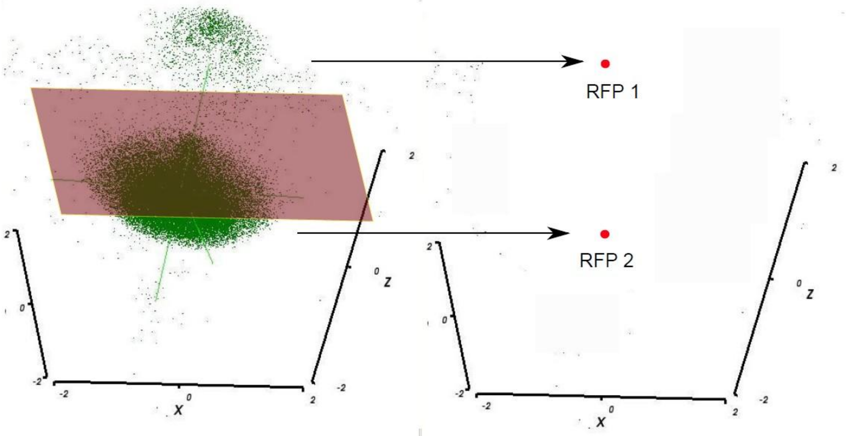


Figure 8: Free space selection by z-Position for the SuperFlux LED: Separating rays with z-values higher or lower then zero creates a two RFP model. RFP1 is located at $z = 0.49$ containing 31% of the luminous flux, RFP2 at $z = -1.76$ with 69%. The global RFP is at the center of the green axis with $z = -0.84$.

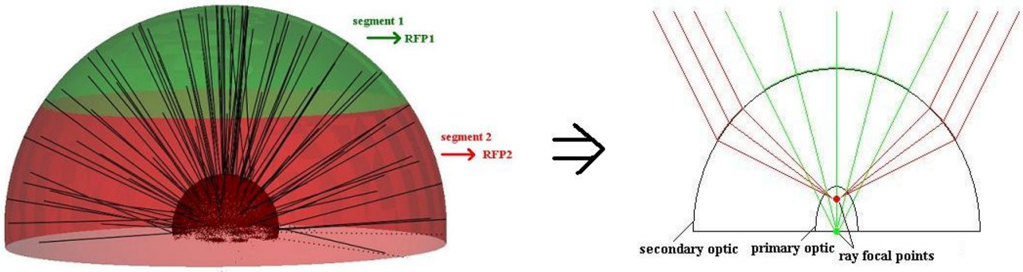


Figure 9: Two sections of the secondary optic (sphere-shaped) define the RFPs: The "green" RFP belongs to rays hitting the inner part of the sphere, the "red" RFP is defined by the outer sphere region

In all cases, choosing a suitable selection criterion requires experience and understanding of the radiation properties of the source. The 3D-views created by the RayAnalyzer can provide some help for that task.
A decision for the number of RFP has to be made to achieve an appropriate balance between and calculational effort and accuracy to meet the requirements of the desired application. The low effort & low accuracy limit is the global RFP summing up all n rays, the theoretically highest accuracy is a n-RFP model, which is basically the rayfile itself.

Nevertheless, there is an additional difficulty arising while defining the multiple RFP model with the Secondary Optic Segmentation criterion concerning the intensity distributions $I_i(\theta, \phi)$. If the standard spatial sum for all rays of the respective partial rayfile is performed and assigned to its RFP, edge overlap effects occur. This means, that a part of the light emitted by the RFP does not hit its related secondary segment and therefore can not not contribute to the design process of this segment. A possible method to reduce the errors of this effect is an adjustment of all rays in the partial ray file:
The direction of each ray is slightly shifted if such a way, that its intersection point with sec-

ondary optic segment stays the same while its starting point is shifted to the RFP. After that, the standard spatial sum for the partial ray file can be performed to get its intensity distribution $I_i(\theta, \phi)$. A symbolic view of the overlap problem and the approach to reduce its error is shown in fig.10.

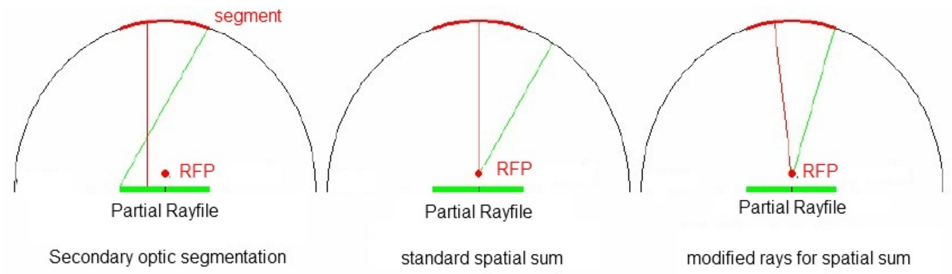


Figure 10: The partial rayfile is defined by the secondary optic segment intersection points (left). The standard spatial sum leads to overlap effects (center) whereas the modified rays still hit there assigned segment (right).

To sum up, by choosing a suited selection criterion for a given rayfile using the RayAnalyzer , it is possible to create a customized multiple RFP model. This model consists of a list of application-optimized points sources in 3D space with assigned intensity distributions. The multiple RFP model represents the extended light sources radiation behavior in a way that combines a easy description and handling with a comparatively high precision in the near field. If it is created with a secondary optic segmentation and the adjusted spatial sum, it is best suited to enable highly effective point source based secondary optical design methods. This is shown in detail in sec.3.

3 APPLICATION IN OPTICAL DESIGN USING TAILORING

This section shows some optical design applications for the source models gained via the RFP techniques presented in chap.2. It is assumed, that the rayfile of the light source is provided and a secondary optical element needs to be designed. The point source based 2-dimensional optical Tailoring is the method used to do the secondary design. Therefore its properties are briefly displayed in sec.3.1.
An example for the application of a Global RFP design is shown in sec.3.2.
Finally, two examples for multiple RFP based designs and secondary optic segmentation are presented in sec.3.3, both consisting of LEDs with more complex primary optics.
The optical systems are simulated using the commercial ray tracing software FRED [7]. Comparing analysis of the resulting illuminance and intensity distributions is performed and presented.

3.1 Optical Tailoring

2D-Optical Tailoring is a design method relying on point sources due to mathematical uniqueness reasons. It can be applied if the necessary parameters like the source intensity, the fixed optical active surfaces (refractive or reflective) and the desired target distribution (illuminance or intensity) are given. By performing a specific algorithm including solutions of differential

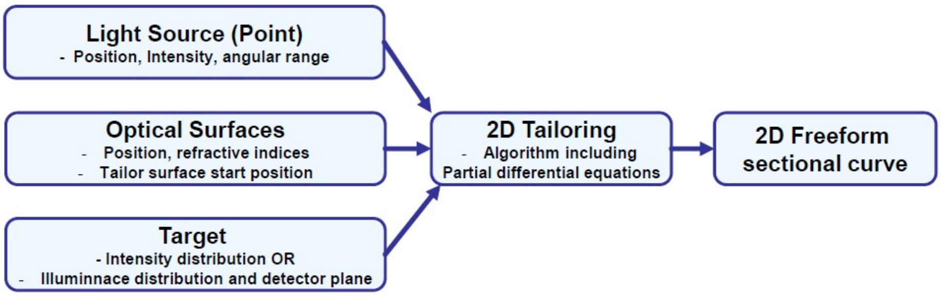
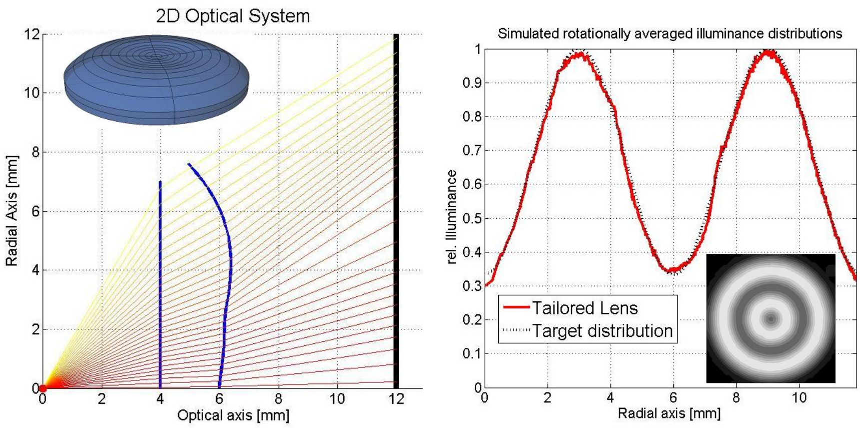


Figure 11: Symbolic View of the 2D-Tailoring process.

equations, a sectional curve of a rotational symmetric freeform surface can be calculated. A schematic view for the tailoring process is shown in fig.11. Within the boundary conditions of this system (point source, rotational symmetry, etc.), the resulting surface is able to provide almost "perfect" results comparing the light output with the desired distribution. A simulated example for a simple PMMA lens is presented in fig.12.



(a) Sectional view of the ray paths (b) Simulated illuminance distributions, rotationally averaged

Figure 12: Results of a 2D-Tailoring process for a PMMA lens with a sinuous radial illuminance distribution

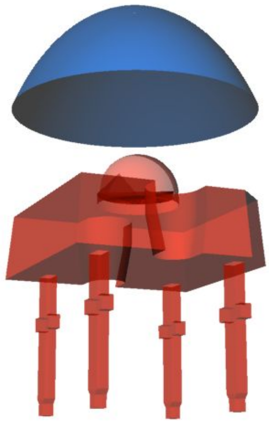
3.2 Using the Global RFP

This section shows a simple example for the application of a Global RFP as a tool to increase the results for the design of a lens.

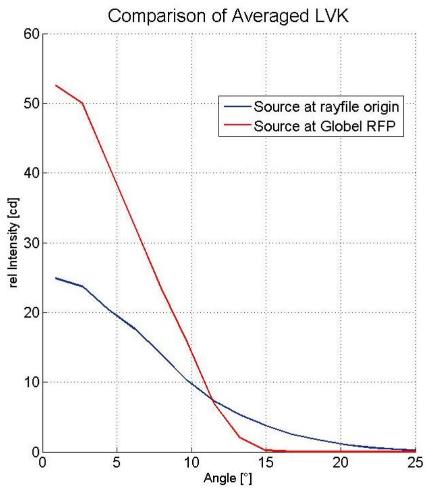
The purpose of the lens is collimating the light emitted by a Luxeon SuperFlux HPWT DL02 (40° Viewing angle) [8] to get a beam as narrow as possible. The PMMA lens with about 8mm diameter is located close to the LED and a plane input surface is given. This setup is displayed in fig.13(a). Rayfiles with different ray numbers can be downloaded from the Lumileds optical resources data base. For some of these rayfiles the rayfile origin is given as for instance the die position.

The standard approach for the design without the RFP is calculating the shape of the lens

with a point source placed at the rayfile origin. The 2D tailored sectional curve is then rotated around the optical axis to get the lens. Plugging the rayfile into the simulation results in the rotationally averaged intensity distribution shown in fig.13(b) as the blue curve.
If on the other hand the RayAnalyzer is used, a Global Free Space RFP for the rayfile can be calculated. This leads to a point source model for the SuperFlux LED which is located at $x = 0, y = 0, z = -0.84$ mm (z-axis equals optical axis). Therefore an enhanced design for the collimating lens with the same intensity distribution but at the improved source position can be performed using 2D Tailoring. The rotationally averaged output intensity disitribution for this design can be seen in fig.13(b) as the red curve. The comparison with the standard approach shows a significantly better performance.



(a) 3D View of the LED and Tailored lens



(b) Comparison of the averaged output intensity distributions

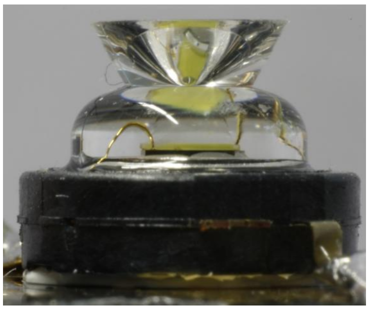
Figure 13: Using the Global RFP for the design of a collimating lens

3.3 Using Multiple RFPS

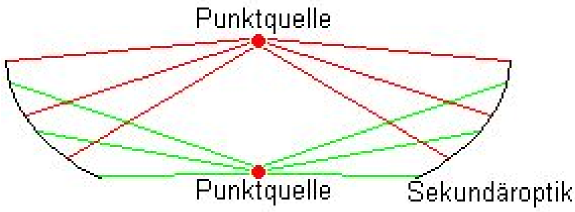
In this section, two examples for Tailored secondary optical designs using Multiple RFP source models are presented. In both cases, beam crossing LED primary optics are involved. The first example contains a side emitting LED and a ring-like lens whereas the other example includes a typical flashlight illumination. Simulation results comparing the standard approach with the multiple RFP based designs are displayed.

Modified side emitting LED
The following design example is based on the Luxeon LXHL side emitting LED that is shown in fig.14(a). The associated rayfile was generated via measurements with a nearfield goniophotometer. Using the RayAnalyzer and performing extended RFP analysis and secondary optic segmentation resulted in the conclusion that a multiple RFP model for this LED for the purpose of near field secondary design cannot achieve improvements compared to a Global RFP. This is due to the fact that there is a large angular overlap of the light emitted by the primary optics TIR surface and the lens surface. Therefore a two-RFP model based on Spatial Division related to the two surfaces can be constructed, but as fig.14(b) shows, each arena of the secondary optic

will be illuminated by both RFPs and prevent an improved design. In terms of multiple RFPs based on secondary optic segmentation, this means that the Free Space Point cloud for each partial rayfile is still spread out and all RFPs have basically the same position in space without decreasing figures of merit Q.

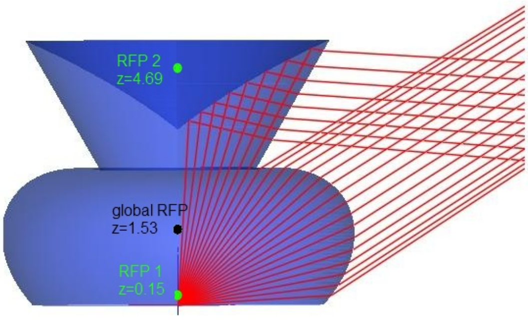


(a) Luxeon LXHL LED

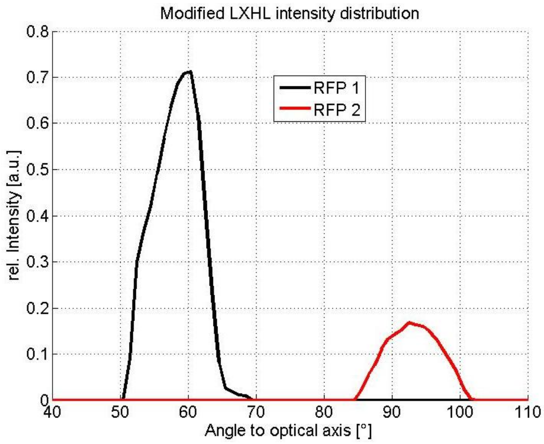


(b) Illumination of a secondary optic

Figure 14: Luxeon LXHL side emitting LED and an assigned two-RFP model based on Spatial Division



(a) Sectional view including the RFP positions



(b) Intensity distribution for RFP1(black) and RFP2(red)

Figure 15: Modified LXHL primary optic

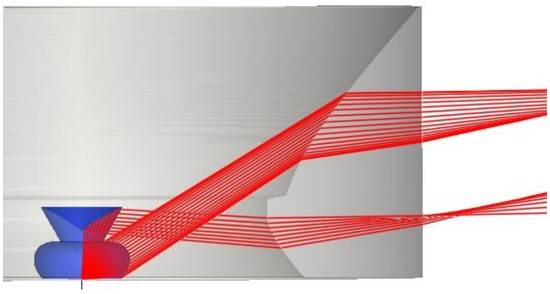
To get an estimate of the possible multiple RFP model improvements, a primary optic similar to the LXHL but with decreased angular overlap was constructed with CAD software. Plugging in an extended LED die, a rayfile was created using standard raytracing. With this rayfile, the RFP analysis with the RayAnalyzer was done. Again, the global RFP turned out to be centered inside the primary optic as expected ($z = 1.53$mm, LED die at $z = 0$). But this time, the Secondary Optic Segmentation criterion (cylindrical shape) results in two RFPs with much more compact Free Space point clouds. This is also reflected in the values for the figures of merit Q shown in tab.1: The figure of merit for the global RFP Q_{global} is about three times higher than the sum $Q_{multiple} = Q_{RFP1} + Q_{RFP2}$ for the multiple RFP model. This is a strong indication, that the multiple RFP model will results in a much better secondary design. A sectional view of the modified LXHL LED with a rayfan and the RFP positions is presented in fig.15(a) whereas

	z position	rel. Q
global RFP	1.53	1
RFP 1	0.15	0.15
RFP 2	4.69	0.18

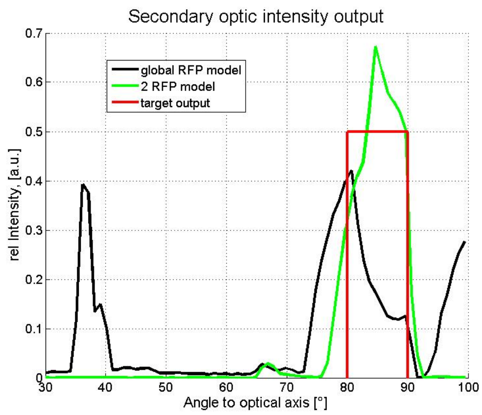
Table 1: Positions and figure of merit values for the global and the multiple RFP models of the modified LXHL

fig.15(b) displays the corresponding intensity distributions.

As an academic example for the secondary optic, an constant output target distribution with the angular range $[80° - 90°]$ to the optical axis was chosen. This corresponds to an "highly" side emitting system which can be of interest for backlighting applications. In a first design process, the ring-shaped two segmented PMMA lens with $50mm$ outer diameter was designed using 2D-Tailoring with the global RFP model. In a second step, a new version of the lens was designed with the two-RFP model described above. Both designs were simulated using the rayfile of the modified LXHL LED. A sectional view of the optical system for this example and the rotationally averaged output intensity distributions are presented in fig.16. The comparison of the output intensity distributions with the desired target curve shows that a significant improvement can be gained through the multiple RFP model.



(a) Sectional view with rayfan



(b) Secondary optic output intensities

Figure 16: Modified LXHL with segmented secondary ring-shaped optic

Flashlight example

The second design example as an application for a multiple RFP model is about a LED flashlight. If glare effects through high luminance need to be avoided, one possible optical setup is using a backwards aligned LED with a beam spreading primary optic in conjunction with a reflector. In this way the high luminance of typical LED flashlight TIR designs can be greatly reduced. A constant circular illumination with 0.8m diameter on a plane located in 2.5m distance of the flashlight serves as target distribution. The primary optic was constructed using Tailoring. The basic setup of this system is displayed in fig.17.

The following design procedure is done similar to the modified LXHL side emitting LED exam-

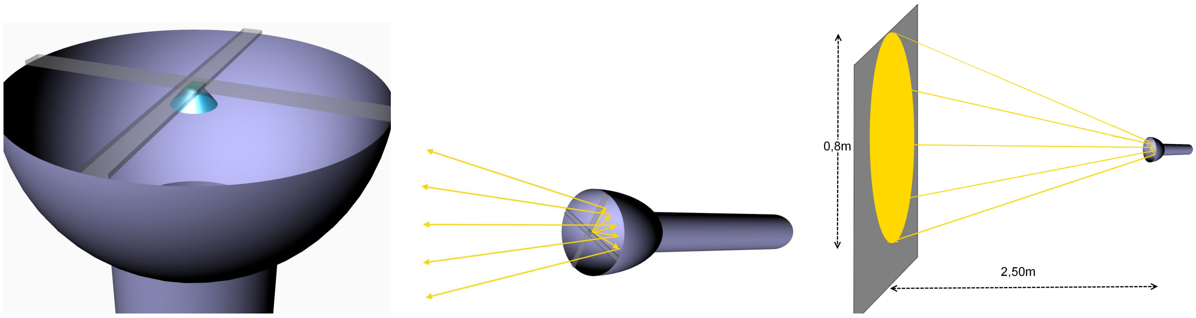


Figure 17: LED flashlight setup: Backwards LED and beam spreading primary optics

	z position	rel. Q
global RFP	1.06	1
RFP 1	-7.72	0.25
RFP 2	2.77	0.38

Table 2: Positions and figure of merit values for the global and the multiple RFP models of the flashlight primary optic

ple from above. The rayfile of a typical white Luxeon Rebel LED [11] is used and 2D Tailoring serves as design method. Again, the first design of the secondary optical element, in this case the reflector, is done with one global RFP. Segmentation of a spherical shape in two suitable parts and applying the RayAnalyzer generates the two RFP model. The detailed values are listed in tab.2. The summed up Q value for the multiple RFP model is noticeably smaller than the global value, again indicating the better source description.

The final results for the LED flashlight are presented in fig.18: The sectional view of the primary optics with a rayfan shows the way the lens and TIR surfaces work to spread the LED light and redirect it to the reflector surface with minimum losses. The figure in the center displays the two RFP positions relative to the primary optic. Each RFP illuminates its own part of the Tailored reflector surface. The simulated illuminance distributions on the detector screen for the Global RFP reflector design and the multiple RFP model are shown on the right side as rotationally averaged sectional illuminance distributions in logarithmic scale. The design relying on the Global RFP with its high center peak followed by an almost non-illuminated ring clearly fails to reach the desired homogeneous distribution. In contrast to that, the design based on the multiple RFP model shows a good agreement with the target illumination.

This section demonstrated possible applications for Secondary Optic Segmentation based multiple RFP models with the help of two examples including LEDs with non-trivial primary optics. The simulation results illustrated a significant improvement of the system performance compared to a global RFP model, which is already a step ahead of standard point source models. But it was also shown, that multiple RFP models have to be defined carefully and application-dependent to get the best results. The analysis of the radiation behavior with the calculational tools presented in this contribution can help to decide what kind of source model is best suited for a specific task.

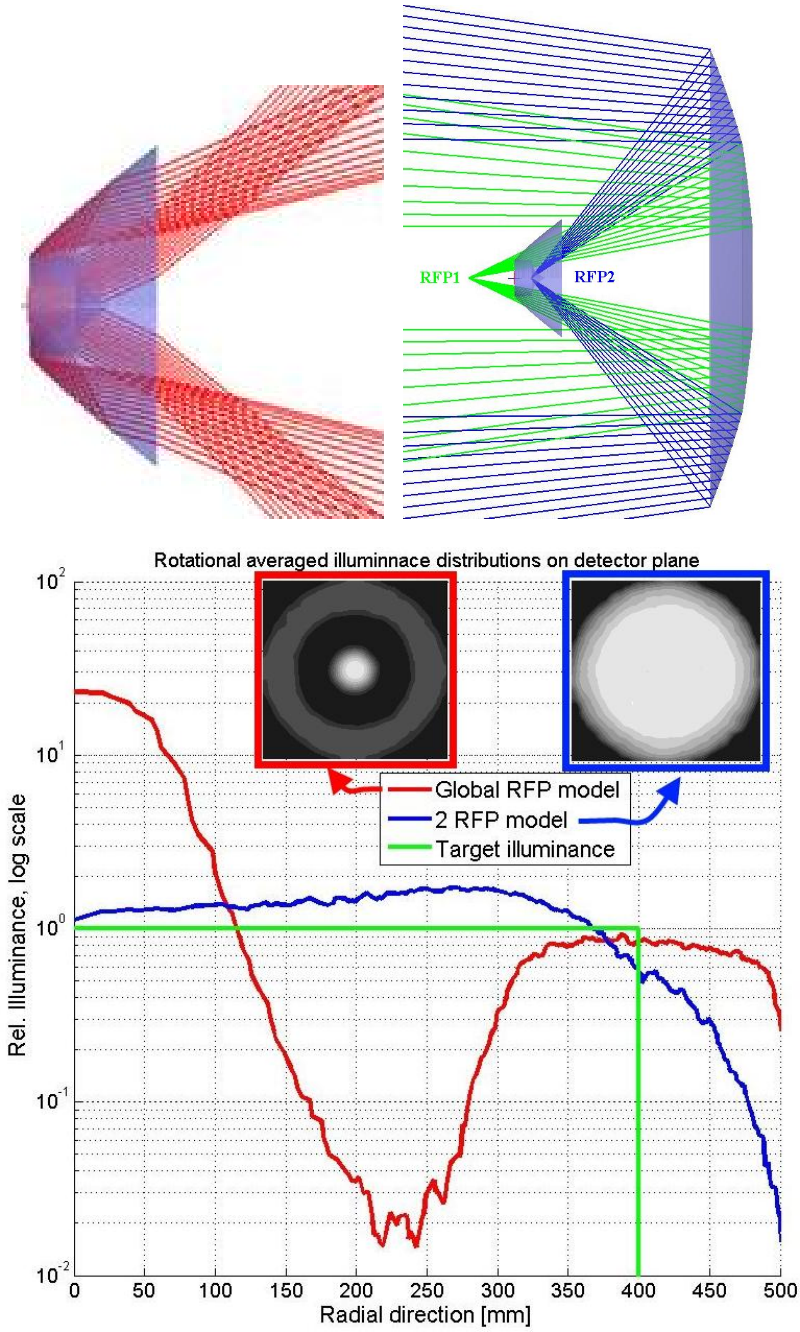


Figure 18: LED flashlight: Beam spreading primary optic (top left), two-RFP model geometry (top right) and illuminance simulation results

4 CONCLUSIONS

This contribution presented a new method to create customized light source models based on rayfiles and analytic calculation tools included in the software toolbox RayAnalyzer . With the help of specific figure of merit definitions, the concept of a Ray Focal Point (RFP) as an optimized point-source-like description for a rayfile was established. Extending this approach led to multiple RFP models which rely on selection criteria as their crucial ingredient. The selection criteria divide the rayfile into a set of partial rayfiles, each assigned to its own RFP. This can be used to separate light originating from different areas like several LED dies or different beam shaping surfaces. Is was shown that a multiple RFP model that is constructed using secondary optic segmentation can increase the performance of 2D Tailored designs significantly.
The methods introduced in this paper are not limited to the LED based examples demonstrated in the previous chapters. Moreover, it can be applied basically to every light source as long as near field data in the form of a rayfile is provided. By using the RayAnalyzer and its graphical and calculational analysis capabilities, the radiation behavior of a light source can be investigated and the possible use and properties of a multiple RFP can be estimated. In general, the more complex a light source is, the more benefit can be obtained using multiple RFP models.

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