A virtual image in the mixing rod

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Mixing rods are used to homogenize light distributions. A detailed look shows that this is only partially true as problems may arise when one tries to image the exit area with a lens. We identify a virtual image of the source inside a glass rod.

1 Introduction

Integrator rods ar an essential element in the optics of some types of data projectors and stage lights. They can be made of glass or in a hollow manner assembled or mirror segments.

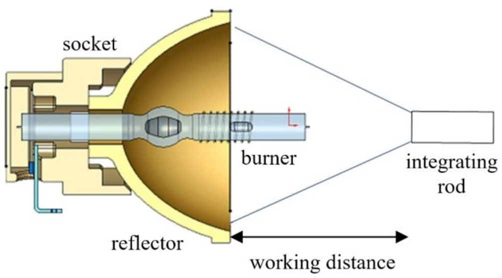

Fig. 1 *Elliptical projector lamp with integrator rod [1]*

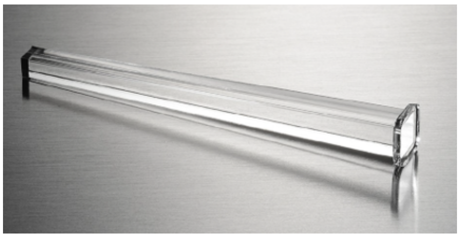

Fig. 2 *Glass rod (courtesy of Auer Lighting)*

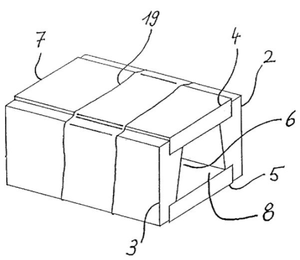

Fig. 3 *Hollow mixing rod [2]*

Glass rods guide the light by TIR (total internal refraction) whereas the segments of hollow rods have to be coated for high reflectivity at grazing incidence. On the other hand, hollow rods provide more efficient light mixing as a function of length becasue in a glass rod, incident rays will be refracted to a smaller angle w.r.t. the axis. And they feature a virtual exit face where no dust can build up (but it can on the segments). However, there's another surprising difference we report about in this paper.

2 Rod and Lens

A somewhat naive notion of a rod's function is that (assuming sufficient length) the illuminance distribution at the exit face is homogeneous whereas the luminous intensity distribution may carry aspects of the source's distribution .

Various implementations try to image the exit face with the help of a lens [3, 4]. In stage lighting, such a system would be even called a "zoom". Unfortunately, the far field image by the lens show rather often some color shades that are more or less an image of the source [5]. It seems as if there is some source structure within the depth of field of the projection lens.

3 Virtual images

The optical designer of a microscope objective lens knows very well that the thickness of any cover glass (a thickness of $0.17mm$ is kind of an industry standard) has to be taken into account. For even larger glass thicknesses or windows on top of a microscopic object, one can observe that a virtual image of the object forms inside the glass and this image suffers from spherical aberration. The same effect should occur in a glass rod.

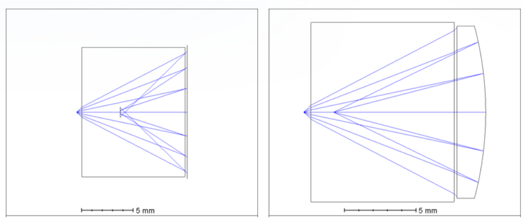

Fig. 4 *Virtual image of an object behind a window*

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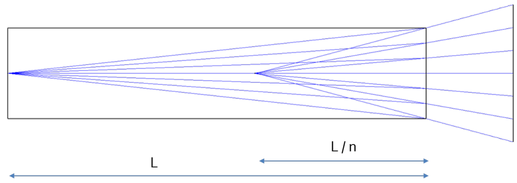

Fig. 5 *Virtual image of the source inside a glass rod*

Indeed, such a virtual image is found; paraxial calculation yields a position of L/n in front of the exit face. Consequently, in a hollow rod there is no image of a color source. In a glass rod, we should also see reflections of the virtual image. All those source images shine through the exit face; thus we may indeed see a coloured far field from the rod with the exit face acting as an exit pupil.

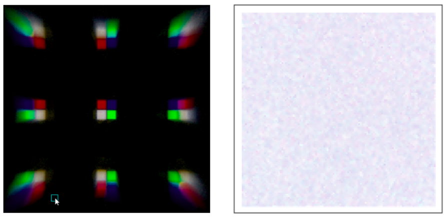

Fig. 6 *Virtual image of a RGBW LED source inside a glass rod (left). Homogeneously illuminated exit are (right)*

4 Solution

The answer of the industry to mitigate the problem and to allow for cheap fresnel lights (a fixture consisting of a source, a rod, and a moving Freslen lens) is to apply some low angle scattering on the exit face of a glass rod [6, 7]. Alternatively, on can place a field lens with a focal length of $f = L/n$ on the exit face. This way, the virtual image is moved away and the projection lens can do its job and produce a well mixed far field without color shades. Aspects if this were discussed in [6].

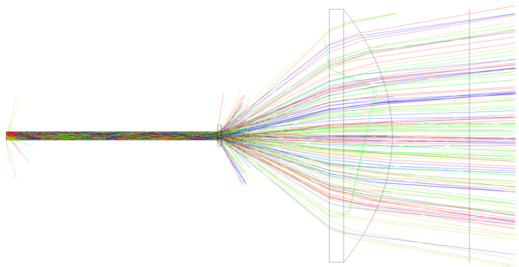

Fig. 7 *Setup with source, rod, optional field lens and projection lens*

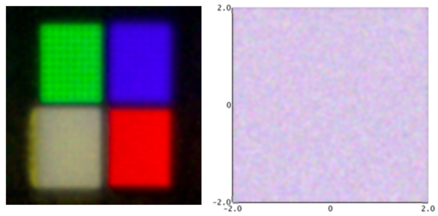

Fig. 8 *Source and homogenized distribution on the exit face*

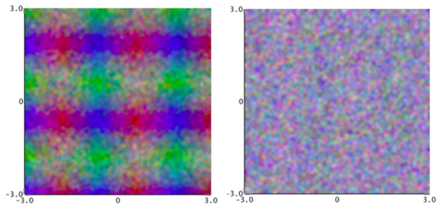

Fig. 9 *Far field after the projection lens without (left) and with field lens (right)*

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